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NOTICE

"BULLETIN" reverts to "IZVESTIYA"

With this, the third English-translation issue to be published by AGI, the translated title of this journal will be carried as Izvestiya of the Academy of Sciences of the U.S.S.R., Geologic Series. The decision to use the term "Izvestiya" instead of "Bulletin" has been made by the AGI Translation Committee to conform with the generally accepted referencing practice of most earth-scientists familiar with Russian literature.

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STRUCTURES OF HYDROTHERMAL URANIUM DEPOSITS AND SOME PROBLEMS OF THEIR STUDY

by

L. I. Lukin and E. P. Sonyushkin

ABSTRACT

In this article there are discussed the problems of the relation between hydrothermal nium deposits and ore bodies as related to tectonic structures. The main structural types the deposits are briefly characterized. The part played by the folded and faulted disloca- s in the localization of uranium minerals are outlined.

* * * * *

GENERAL REMARKS

During the past 10 to 15 years, in con- tion with the development of scientific dies on the utilization of atomic energy, countries of the world have intensified specting and exploration for uranium s, which is still the main source of the sionable material. At first this work ountered considerable difficulties due to absence of serious geologic studies of nium deposits. In particular the struc- al conditions for the localization of hydro- rmal uranium deposits were unknown.

n recent times, in connection with inten- e exploration and investigation, consider- e success was achieved in understanding mode of the distribution and localization ydrothermal uranium deposits. Many blems, however, such as the part played the various factors determining the struc- al conditions of formation of hydrothermal nium deposits, still remain insufficiently estigated and require further fundamental dies. The correct understanding of the ctures of these deposits is especially ortant, as it is one of the conditions for cessful exploration and exploitation.

This article discusses the relation be- en hydrothermal uranium deposits and s, and local tectonic structures. Follow- is a short review of the general tectonic ures of the principal uranium-bearing ions.

I. Some tectonic features of the principal uranium-bearing regions

It is well known that the more important uranium-bearing regions are associated with the border zones of old plains and plateaus and with inner ledges of the old basement in geosynclinal zones.

The Canadian uranium belt is found along the western border of the Canadian plain. The Cornish uranium belt of Cornwall is found on the border of the Variscan plateau. The Katanga uranium deposits are distributed in the downwarp region of the African pla- teau. Examples of uranium-bearing regions associated with terminal folds of geosyn- clines are also known. However, since the time of mineralization, these parts of the earth's crust were transformed into plateau type regions characterized by relatively great resistance. The largest deposits in these regions are in the rocks of the struc- turally higher strata, often in places where the hard basement comes close to the sur- face.

Consequently, the more important uran- ium-bearing regions are always associated with the zones of transition of plateaus into geosynclines and also with the regions of considerable folding within the plateaus.

The geologic situation of the uranium- bearing regions corresponds to their tec- tonic features. These regions are character- ized by pronounced block faulting, indicating considerable strength of the earth's crust. This strength is conditioned not only by the

intense dislocation and metamorphism of rocks of the old basement, but often also by the considerable accumulation of intrusive rocks and volcanic deposits. In isolated regions, granitoid rocks, of three to four successively developing intrusive complexes are produced, while later complexes are characterized by the presence of small, often fractured intrusions.

The upper strata which usually contain the deposits are characterized by the pronounced development of distorted folds. Only in the Katanga region are linear folds observed, but even these are complicated by dome-like structures.

All the uranium-bearing regions are characterized by the exceptionally pronounced appearance of fractures of local significance. As a rule, these fractures are of an early origin and have a long and complex history. In a number of ore-bearing regions they have been the outlet for magmatic flows. They are often accompanied by later magmatic segregation products such as swarms of small intrusions and dikes of acid and sub-alkaline rocks, as well as diabase and lamprophyre dikes.

The above principal tectonic characteristics of uranium-bearing regions determine the main structural features of hydrothermal uranium deposits. In most cases, the latter are fractured and very often appear as complex, vein-like bodies, or linear patterns and more rarely as stockworks of roughly isometric or indefinite shape. In isolated cases, the shape of the ore body is determined by the structure of the layers of the enclosing rocks, the appearance of faults and the development of mineralization in the openings of host rocks.

The depth of the uranium mineralization and the thickness of the deposit are of considerable scientific and practical interest. Unfortunately, only isolated data on this problem are available. The deposits in Canada, Africa and Cornwall are found at shallow depth, but in the literature there are no data on the depth of formation of these deposits. A number of signs such as hypabyssal appearance of intrusives, textural and structural properties of the ores, etc., indicate relatively shallow depths of formation of these deposits. More data on this problem were obtained for certain uranium deposits. Direct observations of the location of individual deposits in the stratigraphic section, and also analysis of other geological facts indicate that their upper portions were formed approximately 500 to 700 m. from the old basal surface.

There are reasons to believe that under favorable structural and lithologic conditions, the total vertical extent of uranium mineralization in hydrothermal deposits is about 1,000 meters. Therefore, it is of importance for the study of the structure of uranium ore-bodies, and for the estimation of the depths of the deposits, to determine their position in the stratigraphic and structural section of the region, while taking into account the depth of erosion.

II. On the role of folding and faulting in the formation of hydrothermal uranium ore fields and deposits

1. Folded structures

In a number of ore-bearing regions the dependence of the uranium deposits on folded structures is quite clearly established. This is the case with the deposits in the Belgian Congo, where streaks of the impregnated ore are distributed in distinct layers of the so-called "ore series."

A similar occurrence is also observed in some part of the deposits in the Rum Jungle field in Australia, where the uranium pitch and chalcopyrite are mainly situated along the planes of stratification and in small cracks in the stratified layers of folded rocks. Other examples of deposits where ore bodies follow the folds of the enclosing rocks are known.

Unfortunately, the role of folded structures in the distribution of the uranium ore bodies was until now obscure. Only in isolated cases was it observed that the ore-bodies are more common near the intersection of early folded structures and more recent ones, with different directions of strike. The more recent folds are accompanied by still more recent granitoid intrusives, which are of about the same age as the uranium minerals.

2. Faulted structures

The part played by faults in the formation of the hydrothermal uranium ore fields and deposits is much better known.

First of all, the important part played by large fractures in the spatial distribution of uranium deposits is already established. This is reflected by the fact that in the majority of ore-bearing regions, the hydrothermal uranium deposits are mainly distributed along large fractures. This is observed, for example, in the Coeur d'Alene area, in the regions around Lakes

abaska and Beaverlodge in Canada, and o in a number of other ore-bearing ions. It must be mentioned that in most es the uranium deposits are usually disuted within 2 to 3 km. of the fractures, rarely at a greater distance from them. racteristically, hydrothermal uranium osits are situated not in the main zones he large fractures, but in the comparaly small faulted dislocations related to large fractures. The openings containing ore are either parallel to the large fracs, or branch from them at acute angles.

consideration of the geologic data from umber of uranium-bearing regions indis that the majority of the large fracs have a long history of development. number of cases they have formed before the formation of the ore deposits were utilized as channels for magmatic . Later, there appeared small intrusions dikes of various composition. Later , the fractures were reopened and then d with hydrothermal deposits. The oreing openings accompanying the large tures also often appeared long before beginning of the formation of the deposand then were several times renewed. ome cases the uranium deposits are ited in faults related to the craters of anoes.

he structural relationship of uranium sits with craters is of great interest, e here are very favorable conditions for formation of joints and their spread to nsiderable depth. One case is known the shoot of uranium ore, associated the neck of a volcano, was more than meters deep, although each was indially short. The structural connection of ium deposits with volcanoes can apparhave a great significance and should aken into account in prospecting and oring. In a number of uranium-bearing ons the ore bodies are situated along s and small intrusions which penetrate the fractures.

he above discussion leads to the conclu that in the formation of hydrothermal ium deposits, a very important part is d by pre-existing tectonic dislocations. ever, it should be remembered that the tures of the deposits are not only ed by means of the renewal of older s. During the process of ore formation openings are usually formed, which play an important part in the structure e deposits.

3. Situation of uranium ore fields with respect to the large fractures

ranium deposits are very unevenly distributed along the fractures. Usually they are grouped in ore bodies which are separated from each other by barren intervals. As regards their location with respect to major fractures, uranium ore fields can be divided into two large groups: 1) associated with the branching of large fractures, 2) situated in the regions of intense development of joints accompanying large fractures.

The first group of ore fields is characterized by the development of well-exposed, ore-bearing fractures and veins, forming a fan-shaped cluster. These zones are of various sizes and often extend over several kilometers. Sometimes they are connected by diagonal cracks forming a complex network of ore-bearing fractures.

The second group of ore fields is characterized by the development of ore-bearing zones, situated near large structures and accompanying the joints connected to the fractures. These ore-bearing zones can occur in various directions with respect to the large fractures -- from parallel to diagonal. Mineralized tectonic zones in these ore fields are often well exposed along the strike and dip, and are often accompanied by small cracks, along which hydrothermal deposition is also developed.

In some cases, it is clear that the accompanying shear zones, which determine the position of the ore fields, branch from the large fractures at changes in the direction of strike.

The propinquity of uranium ore fields to the zones of major fractures can now be definitely explained. It has been proved that the formation of the ore-bearing and distributing cracks is genetically connected to the large fractures. The closing and reopening of these cracks during the processes of ore formation is also due to the movements along the large fractures, which take place simultaneously with these movements.

Naturally, the faulted dislocations are not the only determining factors in the structure of the uranium ore fields. The effect of other factors should also be taken into account, especially the effect of folding, intrusive massifs, and dikes. The depth of the basement, physical-mechanical and chemical properties of the rocks, the surrounding region, etc. The joint effect of these factors on the localization of the ore bodies has not been previously explained.

Further fundamental study of a number of problems related to the part played by faulted dislocations in the localization of uranium ore fields is also necessary. Among these problems are: (a) clarification

of the conditions of dividing of the large fractures and an explanation of the causes of the presence of the ore bodies in these places; (b) investigation of the mode of the spatial distribution of joints, accompanying the large fractures, which determine the distribution of the ore deposits around the fractures; (c) investigation of the structural link between the ore-channels and ore-bearing faulted zones and explanation of the mechanism of control of uranium mineralization by the large fractures.

III. Structures of hydrothermal uranium deposits

Structures of hydrothermal uranium deposits are determined by folding and faulting, the latter being clearly the more important.

For the study of the folded structures of uranium deposits there is first of all required the knowledge of the type of the folds formed by the rocks enclosing the ore. One should mention that the method of formation of the fold strongly affects the localization of the deposits and ore bodies.

The data found in the literature is insufficient for satisfactory explanation of the significance of folded structures in the formation of hydrothermal uranium deposits. In particular, there are no data on the relation between uranium deposits, and shear, block and diapiric folds. It is true that there is preliminary information on the part played by diapiric folds in the formation of certain deposits in the Katanga region. There is also no data on the effect of drag folds on the localization of the ore bodies. The structural conditions of formation of the ore bodies present within the strata of the enclosing rocks, are either only very schematically elucidated or completely unknown. So far, the part played in the formation of ore-bodies by faults, cavities between the folds, and small cracks connected with the deformation of the folds is not sufficiently explained. For a number of the deposits the exact understanding of the part played by replacement in the formation of the ore deposits is required. The correct understanding of the structural conditions of formation of uranium deposits in folded strata is impossible without the full solution of the above problems.

For the structural study of hydrothermal deposits of the joint type, it is first of all necessary to determine the genetic type of the ore distributing methods and ore-bearing joints. The depth of the ore shoot largely depends on whether it is associated with a shear joint or whether it fills a fault.

The direction of the relative displacement of blocks along shear joint is also important, as it makes it possible to estimate the probable position of openings, which are often accompanied by bodies of ore. In addition to the usual methods for the determination of the directions of displacements, in a number of cases the investigation of the spatial distribution of horsetail faults, which develop during movements along the main shear fault is very convenient. The use of microstructural analysis is also recommended. The importance of horsetail faults is also due to the frequent development of bodies of uranium ore in the places where they join the main shear fault. Therefore the location of the horsetail faults and also the determination of their spatial relationship with the shear cracks, and the determination of the rules of their distribution, are one of the important problems in the understanding of locating uranium deposits.

The determination of the relationship between the ore bodies and faulted dislocations is a particularly important problem in the study of hydrothermal uranium deposits. These dislocations can be either older or younger than the ore deposits. In the first case, the tectonic dislocations are the important factors in the structure of the region before ore-formation, which localize the ore bodies. In the second case, such dislocations cross the ore bodies, which are already formed, and displace parts of them.

The understanding of the history of the development of the faulted displacement in the region of the deposits, and their effect on the deposition of the ore bodies constitutes another chapter in the structure study of the deposits. While not attempting to discuss the criteria of the differences between the dislocations taking place before and after the ore formation, we should emphasize that in some cases the solution of this problem is very difficult. It is enough to point out that in prospecting for hydrothermal uranium deposits cases are known where the dislocations formed before the ore-formation have been mistaken for post-ore dislocations, resulting in considerable expense connected with the search for the displaced parts of the ore body. A detailed study of the relationship between the ore bodies and the faulted dislocations indicated the pre-ore age of the latter. In consequence, the direction of prospecting was changed.

Studies of the hydrothermal uranium deposits indicate that their formation takes place in many stages. In most cases, the uranium minerals are formed in veins during the final stages of the mineralization. Thus, the spatial localization of the bodies

ranium ore is affected not only by the ements taking place before the ore for- on, but also by the intramineralization ements, which are responsible for the ation of the uranium-bearing veins and lets. The latter are often due to the g of the cavities formed during these ements, and also to the filling of joints ed during the division of the enclosing s, or older veins.

he above considerations lead to the con- on that an understanding of the struc- conditions of the localization of the ore s is not possible without understanding principles of the intramineral tectonics. ould be remembered that the area of mineral deformation is usually smaller that of the earlier movements. These rmations can usually be detected not the whole of the pre-ore tectonic dis- ion, but in the weakest sectors. The tigation of the laws of intramineral al dislocations is very important as information is necessary for the loca- of the sectors of possible concentra- of uranium ore. The determination of irection and the character of these ments in the process of formation of ranium ore permits the localization of re deposits in joints. The study of mineral tectonics is closely related to etection of the veins of various ages, are characterized by definite mineral lexes and distinct spatial boundaries.

e differentiation between the various tural types of hydrothermal uranium its is very difficult due to the lack of mation on the deposits in different geo- conditions. The separation of the ture of uranium deposits into groups, is discussed below, is not intended e full explanation of the problem, but general description of the part played ructures in the localization of deposits.

should be mentioned, that individual its, and sometimes parts of the depos- can be referred to different structural , or can be characterized by the feat- which are transitional between different . At present, it appears possible to guish between the following principal of structures of hydrothermal uranium its.

1. Deposits accompanying areas entroclinal closure of strongly folded ynclines with steep flanks (fig. 1)

e main bodies of ore in deposits of ype develop on the contacts of rocks ried lithologic composition and mechanical properties (for example, siliceous rocks and carbonate-shale strata). They are shaped

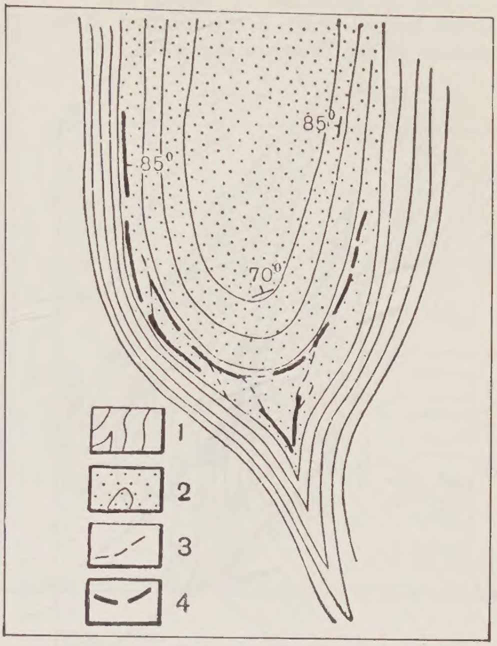


FIGURE 1. Structure diagram of a deposit in an area of centroclinal closure of a strongly compressed syncline with a steep flank (plan).

1 - chert;

2 - shale-carbonate-stratum;

3 - pre-ore tectonic faults;

4 - ore bodies.

as lenses, with veinlet impregnation type of mineralization, and are distributed parallel to the enclosing strata. These ore bodies are often large, and are situated both in the areas of closure of the folds and in the neighboring areas of the flanks. There are also ore bodies accompanying faults situated in the area of closure of the folds. It should be remembered, that the analogous structural conditions can be observed in the areas of periclinal closure of anticlines, and therefore the possibility of finding hydrothermal uranium deposits there is not excluded.

2. Deposits in areas of steep flexure complicating the flanks of strongly compressed folds (fig. 2)

The ore bodies in these deposits are

large, flat or lenticular, and their deposits are conformable. The folded structures are considerably complicated by normal and horizontal faults, which are important in the localization of the uranium deposits.

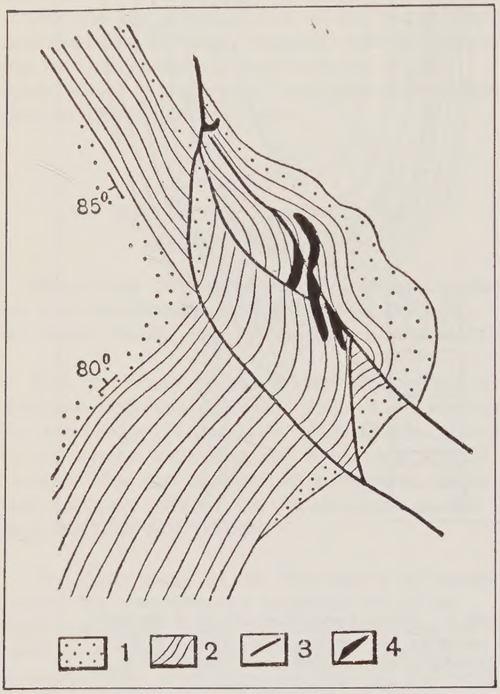


FIGURE 2. Structure diagram of a deposit in an area of a steep flexure, complicating the flank of a strongly compressed fold (plan).

1 - shale stratum;

2 - chert;

3 - pre-ore tectonic faults;

4 - ore bodies.

3. Deposits in individual points or in a series of parallel shear zones

These deposits are usually well exposed both in the direction of strike and dip, but the width of ore bodies is small. As a rule, the ore-bearing joints are quite straight, but in places they form wide bends. In some cases they are accompanied by rare apophyses connecting neighboring ore-bearing joints. The latter are often situated close together and form shear zones with ore bodies in echelon. These ore bodies have the shape of flat lenses, separated from each other by considerable barren intervals.

4. Deposits in complex shear zones accompanied by horsetail faults (fig. 3)

Deposits of this type are characterized by large ore-bearing tectonic zones and great complexity of structure. Each such zone has a number of usually long and closely spaced shear joints, accompanied by finely sheared and shattered rock. Very often the joints branch into many diagonal shear cracks and faults. The ore bodies in deposits of this type have more complex shapes such as veins, lenticles, columns and irregular masses. The size of the ore bodies is variable.

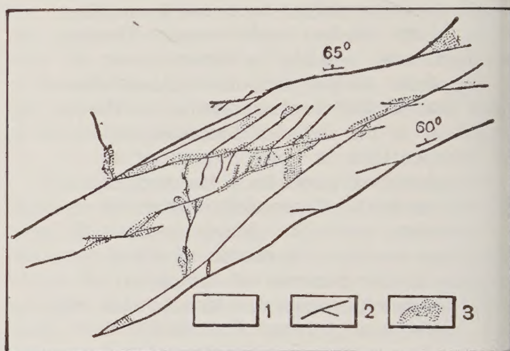


FIGURE 3. Structure diagram of a deposit in complex shear zones with horsetail joints (plan).

1 - enclosing rocks; 2 - pre-ore tectonic zones; 3 - ore-bearing areas.

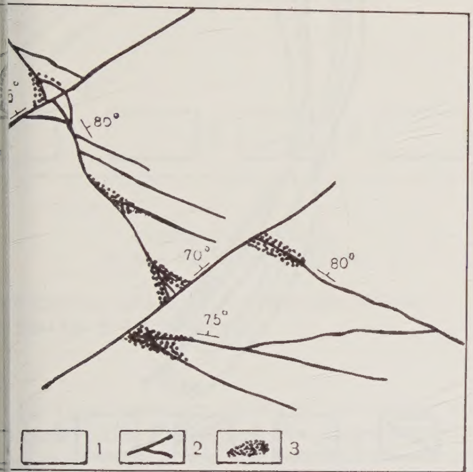
5. Deposits in the areas of intersection or connection of pre-ore tectonic zones (fig. 4)

The ore-bearing zones of these deposits are often inclined with respect to the directions of strike and dip and are accompanied by many small horsetail shear joints and faults, which form characteristic stockwork. The ore-bodies have the shape of flat lenses and are grouped in columns, accumulating towards the zones of contact between the pre-ore tectonic zones. The depth of these columns is several times greater than their length.

6. Stockworks and fractures between branching fractures (fig. 5)

Deposits of this type are situated in narrow, wedge-shaped blocks of rock limited by branching fractures. They are usually characterized by large bodies of irregular, often elongated shapes, with stockwork

:ribution of the minerals. The stockworks represented by a net of small, closely-ced cracks, oriented in various direc-ıs. The bodies of ore are localized in as of most intense joint development. y are usually situated nearer to one of branches of the fracture and are distri-ed along this branch. When the fractures accompanied by intrusive granitoid rocks, stockworks develop mainly in these rocks, owing their shape to a considerable de-e. The areas of the economic ore bodies be of considerable size.



JRE 4. Structure diagram of a deposit an area of junction and intersection of pre-ore tectonic zones (plan).

enclosing rocks; 2 - pre-ore tectonic s; 3 - ore-bearing areas.

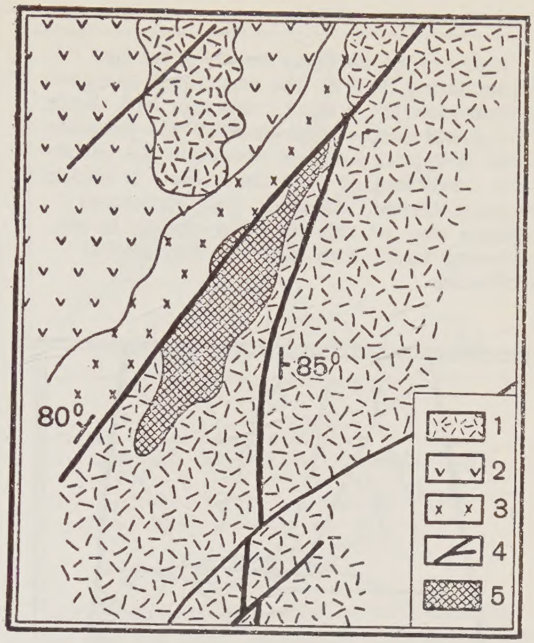


FIGURE 5. Structure diagram of a deposit represented by a stockwork situated between converging fractures (plan).

1 - porphyritic tuff; 2 - diorite; 3 - syenite; 4 - tectonic dislocations; 5 - ore-bearing areas.

tockwork zones within small intrusions and dikes (fig. 6)

he deposits of this type usually develop e area of contact between small intru-and dikes and the enclosing strata, ıg different mechanical properties. these contacts are usually situated ore faulted displacements, sometimes npanied by horsetail joints. The bodies e accumulate in the direction of the ure zones, but are situated at a cer-distance from them, and are associated the areas of numerous small cracks. have the shapes of complex lenses, ated in the direction of the fractures. me cases the ore-bearing stockworks mplex shape are distributed at the contacts of the extrusive or intrusive bodies, without any visible connection with the faulted dislocations.

The above classification does not include all the complex of factors affecting the formation of hydrothermal uranium deposits. A classification which would reflect in the required degree the geologic conditions of formation of hydrothermal uranium deposits is very much needed.

Among the many other problems requiring investigation is the effect of change in the structures of uranium deposits with depth. Unfortunately, there are so far very few reliable data on this problem. Isolated examples indicate that the ore-bearing shear joints, which are clearly evident in the upper parts of the deposits, begin to split at greater depths into a number of tectonic seams, which at still greater depth pass into a series of small cracks, forming the bottom of the deposit. Such change of structures with depth has been followed by mining over a vertical distance of 700 to 800 meters, and there is no basis for connecting it with the effect of rocks with different

mechanical properties.

There is no doubt as to the need for accumulating data on the structural changes of hydrothermal uranium deposits with depth. This would enable estimation of the possible depth of deposits and to ascertain the structural conditions of their formation. It should be remembered, however, that structural changes may be affected by a change in the enclosing rocks with different mechanical properties.

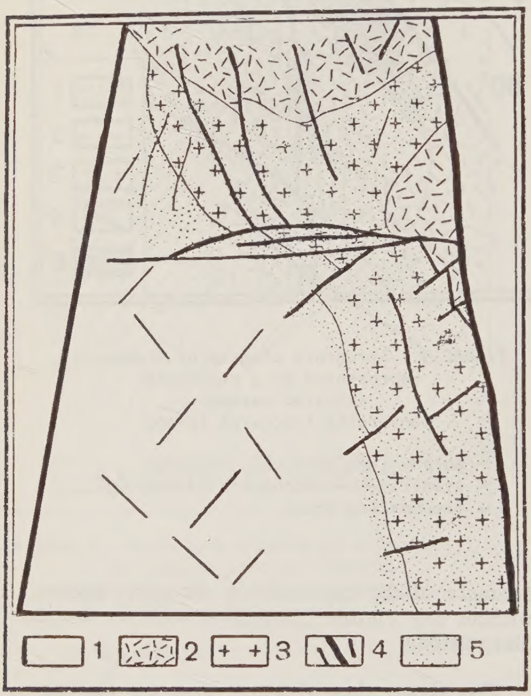


FIGURE 6. Structure diagram of a deposit represented by a stockwork zone within a small intrusion (section).

1 - porphyrite; 2 - extrusive tuff; 3 - intrusive quartz pophyry; 4 - pre-ore tectonic dislocations; 5 - bodies of ore.

IV. Structural conditions for the localization of ore bodies in hydrothermal uranium deposits

While studying the hydrothermal uranium deposits the geologists of various countries have determined the principal conditions for the localization of ore bodies with respect to the structural properties and characteristics of the enclosing strata. It was found that formation of ore bodies in these deposits took place mainly by filling open cavities, although in a number of deposits replacement was very important. A review of the structural conditions for the localization of uranium ores in hydrothermal deposits leads to the distinction of the following main structural types of ore bodies: (1) Conformable ore bodies in the additional steep inflections complicating the flanks and closure areas of strongly compressed synclinal folds (fig. 7).

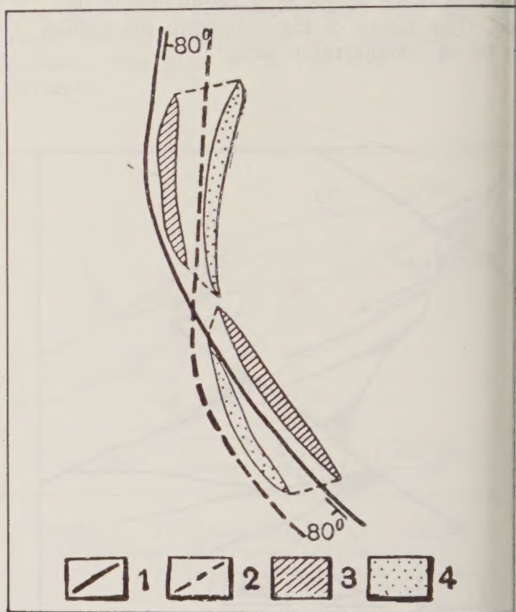


FIGURE 7. Conformable ore bodies in additional steep inflections complicating the flank of a strongly compressed synclinal fold (plan).

1 - line of contact between chert (left) and calcareous-shale (right) in the upper strata; 2 - line of contact in the lower strata; 3 - ore body in the upper strata; 4 - ore body in the lower strata.

Ore bodies of this type have the shape of flat lenses of various, and often considerable, sizes. They are usually deposited conformably with the direction of strike of the enclosing rocks and are characterized by the development of impregnated and finely veined ores.

(2) Ore bodies in the fault zones which formed in areas of abrupt closure of strongly compressed synclinal folds (fig. 8).

These ore bodies have the shape of flat lenses corresponding to the stratification of the enclosing rocks. Uranium pitch appears as veinlets. Individual bodies are relatively small.

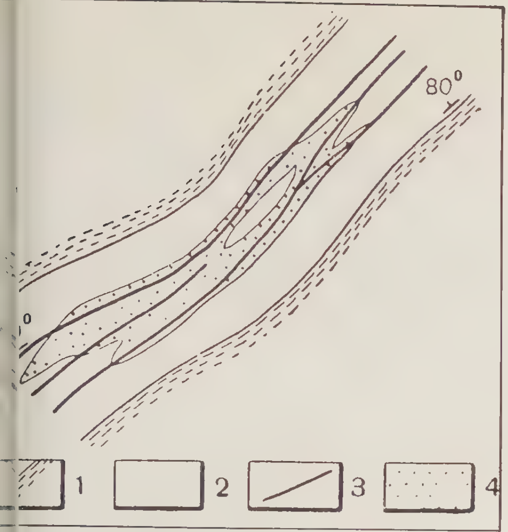


FIGURE 8. Ore body in the fault zones (plan).

micaceous shale; 2 - calcareous shale; faults; 4 - ore body.

(3) Ore bodies in areas of horizontal and rtical inflection of ore bearing fractures. e main reason for the localization of ore dies in the bent parts of the tectonic acks is the formation of cavities, in conction with movement along the cracks ring mineralization. The ore bodies in ese areas are usually flat and elongated ses of various sizes.

(4) Ore bodies in areas of intersection branching of pre-ore tectonic zones and acks. In these areas the rock is most attered. The ore bodies, shaped like egular columns or flat lenses of variable e, dip in accordance with the line of ersection of the pre-ore structures. They e most clearly shown in the areas of ersection of steep ore-bearing fractures d dipping faults. Often the ore-bearing actures near the intersecting or limiting slocations branch into a number of veins, forming stockworks and T-shaped lumns of ore.

(5) Ore bodies in areas of contact been main and horsetail joints (fig. 9).

The ore bodies of this type have in genal the shape of columns which dip accord- to the contact lines of the cracks. The e is more often developed along both acks near their point of jointing, including

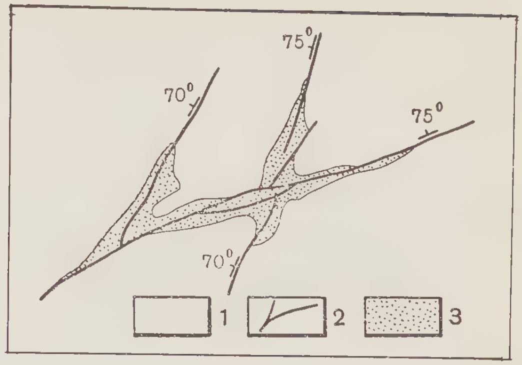


FIGURE 9. Ore bodies in areas of contact between main and horsetail joints (plan).

1 - enclosing rocks; 2 - tectonic dislocations; 3 - ore bodies.

also the wedge-like block of rock between the cracks. Quite frequently the ore is found only in the horsetail joint.

(6) Ore bodies covered by tectonic dislocations and dikes (fig. 10). The position of ore bodies of this type is determined by the underlying surface in the path of ore solutions. Such surfaces can consist of pre-ore tectonic zones and cracks, contact surfaces between dikes or earlier veins, and finally stratified beds, in particular when the surfaces between them contain gouge. The ore bodies have the shape of complex layers,

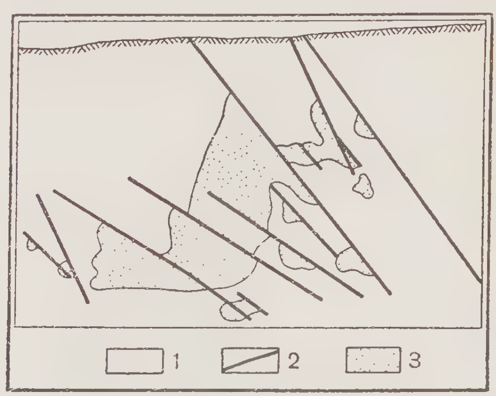


FIGURE 10. Ore bodies covered by tectonic dislocations (vertical projection).

1 - enclosing rocks; 2 - pre-ore tectonic dislocations; 3 - ore bodies.

dipping in accordance with the beds of the relevant structures.

(7) Ore bodies in areas of intersection of ore-bearing fractures with dikes, earlier veins and rocks, favorable for mineralization (fig. 11).

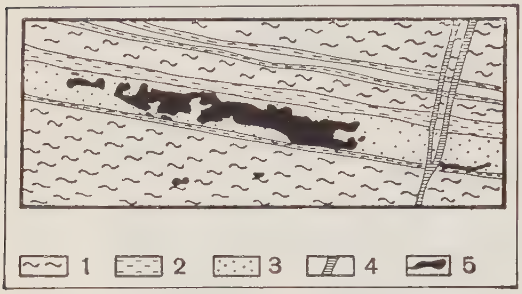


FIGURE 11. Ore bodies in areas of intersection of an ore-bearing fracture and a favorable rock formation (section in the plane of the vein).

1 - sericitic shale; 2 - quartz shale; 3 - chlorite shale and pyrite; 4 - granite dikes; 5 - ore bodies.

These bodies are often found in places of intersection of ore-bearing fractures and dikes of various composition. In other uranium deposits the ore bodies are associated with areas of intersection of ore-bearing fractures and earlier sulphide veins. Finally, in some deposits, there is observed the prevailing association of the ore bodies with the places of intersection of the ore-bearing fractures with fractures in the rock strata favorable for mineralization. The spatial connection between ore-bodies with amphibolite beds is observed in deposits in North Saskatchewan (Canada). The ore deposits of Rum Jungle (Australia) accumulate near coal and graphite shales. One case of uranium ore bodies associated with fractures in pyritic rocks is also known.

The association of ore bodies with intersections of dikes, earlier veins, and favorable rock formations can be due to two main factors. One of them is the intense joint formation in such areas, due to the maximum mechanical heterogeneity. The other factor is apparently the favorable chemical composition of the enclosing rocks and earlier veins. It is possible that they act as precipitators of the uranium minerals due to the presence of organic substances, sulphides, and other minerals containing bivalent iron. This problem is not sufficiently understood and requires further investigation.

(8) Ore bodies in areas of small fracture development (fig. 12).

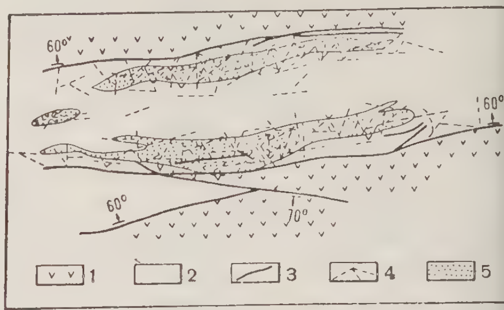


FIGURE 12. Ore bodies in areas of small fracture development (plan).

1 - porphyritic tuff; 2 - dike of quartz porphyry; 3 - pre-ore tectonic dislocations; 4 - systems of small fractures; 5 - ore bodies.

These ore bodies are common in stockwork deposits. They are more frequently found within small intrusions and dikes, usually near fairly large tectonic zones. The ore bodies of stockwork type have shapes of complex columns or flat elongated lenses, and are often large.

The above structural types of the ore bodies obviously do not include all the variations of the natural conditions of uranium ore localization in hydrothermal deposits.

Further accumulation of data elucidating the connection between the ore bodies and the structures, and the causes of these connections, is necessary. However, the facts discussed above already indicate, that the structural conditions of localization of uranium deposits and ore bodies in general do not differ from those of low temperature hydrothermal deposits of other metals.

CONCLUSIONS

The above data indicate, that at present, considerable success in the study of the structural conditions of formation of hydrothermal uranium deposits has been achieved. However, it must be stated that many problems require further study. Of these problems the following should be particularly emphasized:

1. Clarification of data on the depths of ...rmation of hydrothermal uranium deposits ...d on the vertical distance of development ... uranium mineralization.

2. The determination of the part played ... folded structures in the distribution of ...anium ore fields and deposits.

3. Further study on the problem of ...uctural relation between the ore fields ...d deposits and large fractures.

4. Clarification of the part played by ...junctive folds of various genetic types in ... localization of uranium deposits and ore bodies.

5. Investigation of the laws by which the structures of uranium deposits change with depth.

6. Further studies on the causes of prevailing localization of ore bodies in favorable rocks, and on the part played by replacement in the deposition of uranium ores.

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ROCK RADIOACTIVITY STUDY IN THE NORTHERN CAUCASUS AND ITS IMPORTANCE FOR CERTAIN PETROLOGIC PROBLEMS (PRELIMINARY CONCLUSIONS)[1]

by

G. D. Afanas'yev and S. G. Tseytlin

INTRODUCTION

Thanks to the work of a large team of petrographers, the main evolution features of the magmatic activity in the North Caucasian folded province are now known. Detailed geologic and petrographic studies involving methods of absolute age determination were carried out in the North Caucasus. These studies elucidated the sequence of formation in time and space of the principal eruptive rock associations. This work revealed the complexity of the geological development of the North Caucasus as a structural unit of the Earth's crust during the interval from the Lower Paleozoic to the present time. The conclusions from the studies on magmatic activity in the North Caucasus are collected in several published papers [3-5]. Referring the reader to those papers for geologic and petrographic details, we give here only the schematic representation of the present day separation of the magmatic rocks in the North Caucasus into complexes of various age, and their distribution in the structural zones of the North Caucasus folded province.

I. Distribution of radioactive elements in rocks of magmatic complexes of various age in North Caucasus.

The distribution of rare elements in rocks is of considerable interest for modern geology and particularly for some branches of geology such as radio-geology and petrology. Especially important for the study of the causes of endogenous processes, particularly magmatic, which were, and still are taking place in the Earth's crust, is the investigation of the distribution of radioactive elements in rocks. Consequently, the determination of the distribution of radioactive elements in eruptive rocks in the North Caucasus was required for the detailed study of magmatic geology of this region.

Usually, in geochemical work (K. Rankam, A.P. Vinogradov, et al. [7, 14]), averaged data on the radioactivity of acid rocks or granites are used. Systematic investigation of the magmatic history of the North Caucasus makes it possible to publish (for this single structural province) the preliminary data on the radioactivity of granitoid rocks of various ages and petrographic types which are partly of different origin. This is of even greater interest since, as shown in Table 1, the magmatic activity of the North Caucasian folded province was several times rejuvenated from the Cambrian to the Quaternary period.

The full characterization of the radioactivity of rocks of all the complexes and various ages in the Caucasus, with all their differences and facies variations, is still far from complete. However, the available data give the preliminary characterization of the rocks of the North Caucasus, including their age and petrographic properties.

Tables 2 to 8 give the data on radioactivity and some chemical properties of magmatic rock complexes of various ages in the North Caucasus. Also presented are the molecular ratios Na_2O: (Na_2O + K_2O) expressed as percent and called the coefficient "n"; a similar Th:U ratio was called the coefficient "r".

Tables 2 to 8 give also the results of analyses for SiO_2, K_2O and Na_2O along with the content of radium, uranium and thorium of massive rocks. Granitoid rocks, represented by the granitoid complexes of various ages and with specific relative contents of potassium and sodium, were mainly used in

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e radiochemical analyses.

Changes of radioactivity during the devel-ment of the magmatic process were inves-gated using intrusive rocks, and accom-nying pegmatitic and aplitic phases as an ample.

Finally, it was of interest to describe e distribution pattern of radioactive ele-ents in granitoid magma of various ages. r this purpose, in addition to the radio-emical analysis of massive rock samples, e accessory minerals with specific weight eater than 2.8 were separated and studied radiochemical methods.

The articles by A.P. Vinogradov [7] and F. Birch's "Heat from Radioactivity" [16] ve data on the radium content of granite, d basaltic rocks in various parts of the rld and also the characterization of rocks ouped according to their age, or forma-n of definite complexes. The article by S. Larsen and G. Phair [20] gives data on e radium and thorium content of various cks in different regions. All the authors ually mention the uneven distribution of dioactive elements in rocks even when y belong to the same petrographic group; for example the granites or basalts. Birch believes that uranium and thorium ve the tendency to concentrate to a greater gree in granites and to a lesser degree in rabasic rocks, thus confirming the fact own earlier. His second conclusion, garding the strong tendency of uranium, rium and radium content to increase with increasing content of silica is also not v. It requires certain corrections in the ht of studies on the radioactivity of grani-d rocks in the North Caucasus. Both the ove empirical rules when generalized, do agree with many facts found in nature.

The distribution of radioactive elements eruptive rocks can be better explained making the following, very important and ongly corroborated assumptions:

1. Magmatic activity in the Earth's crust due to the periodic appearance of mag-tic foci on various levels.

2. The world-wide study of magmatic ivity in folded regions indicates two types association in eruptive rocks: (a) basic l ultrabasic rocks, accompanied by grani-d intrusions of the plagiogranite -- sodium e and classified according to the predom-ting alkaline metal; (b) rocks of the rite-granodiorite type, accompanied by assium granite intrusions. The differen-ion between the two types of granitoid ks when related to the development of ptive rock associations of various origins, is of considerable importance for the understanding of the distribution of radioactive elements in eruptive rocks. Without considering the composition of the individual granitic massives, which are correlated with the phenomena of hybridization and assimilation, i.e., with the local complications, it is possible to separate two quite different types of granite. These two types of granitoids are identical according to their texture and content of free silica in the form of quartz (SiO_2 about 75%). However, as regards the ratio of their alkalis, they are quite different.

The study of radioactive elements in eruptive rocks in the Caucasus and of their petrochemistry indicates that the radium, uranium and thorium content is almost identical in plagiogranites of the Urushten complex (the first type of association of rocks) and in basic rocks of the North Caucasus (diabases 179/56 and 481/56). These data agree with the corresponding figures collected in "Nuclear Geology" [15-17]. In acid and in sodium richer varieties of plagiogranites, the radioactive element content increase approximately two-fold. In the separated heavy mineral fractions (specific weight greater than 2.8) the radium, uranium and thorium content increases correspondingly to their content in the massive rocks -- for plagiogranites 15-20 times, and for plagioalaskites nearly 100 times. However, the ratio of thorium to uranium remains generally constant in all cases. For convenience of comparison -- following the petrochemical convention of expressing the alkalinity of a rock as the coefficient "n", representing in percent the corresponding ratio Th:U by the coefficient "r". Table 2 indicates that "n" and "r" for the massive rocks and for the separated fractions are the same for granitoid containing different amounts of silica and sodium (i.e., for granitoid representing consecutive variations of granitic magma of the first type). Upper Paleozoic granitoid is characterized by the preponderance of potassium over sodium, and consequently its ratio of uranium to thorium is higher. It should be mentioned that the hypabyssal facies (granitoid of small intrusions) is richer in radioactive elements; in this case the increased importance of thorium is noticeable. The thorium enrichment of the upper Paleozoic magma can be more satisfactorily explained by the assimilation of rocks of lower Paleozoic substrata (Urushten complex). This is particularly pronounced in rocks of an early formation stage as small intrusions such as diorites. On the other hand, the tendency of enrichment with radioactive elements, particularly uranium, of satellites of upper Paleozoic granitoid intrusions is observed in specimens No. 409/50 and No. 30/50 (table 4).

TABLE 1. Distribution of associations of eruptive rocks of various ages in the structural zones of the North Caucasus.

Geologic age	Magmatic complexes	Frontal fold zone and Northern subzone		Zone of longitudinal valleys	
		Formation	Abs. age in mln. yrs.	Formation	Abs. age in mln. yrs.
Tr-Q	Cenozoic	1. Liparite-andesite formation. Liparite, tuff, extrusions.	-	1. Liparite-andesite formation. Liparite and andesite lava from Iire, Kyugen-Kaya.	-
		2. Trachyte formation: extrusions of trachiliparite.	30	2. Formation of Eldzhurtin granite.	50
J-Cr	Mesozoic	1. Liparite-andesite-porphyry formation: andesites, dacites, liparites. (Karachev region).	120	1. Liparite-andesite-porphyry formation: liparite, dacite andesite ("keratophyres") (Sadon, Fasnal, Umpyr Pass).	80
C_1-P	Upper Paleozoic	1. Formation of paleoliparite, andesite and dacite (Malaya Laba, Khatsavitaya, Teberda) (Possibly later!)	No results	1. Formation of M1 granites: alaskite, microcline biotite granites (substrata-granodiorites, fragments of lower Paleozoic crystalline rock substrata.	200
		2. Formation of small intrusives: Yatyrgvartin type granite, diorite.	200-180		
		3. Formation of small Indysh type intrusions: alaskite, granite, diorite.	200-240		
		4. Formation of granitoids of block elevation (Dakhovskaya, Eshkaton, Malka): Alaskite, granite, granodiorite.	180 (alaskites)		
CmS-D_1	Urushten magmatic complex	1. Formation of sodium gneiss granites: (a) pegmatite, aplite, (b) Na-granite, porphyry-granite, (c) tonalite.	310-320	Substrata penetrated by upper Paleozoic and later intrusions.	
		2. Ultrabasic rocks.	320		
		3. Gabbro-amphibolite.			
		4. Diabase-keratophyre formation.			

TABLE 1. (Continued)

Geologic age	Magmatic complexes	Granitoid zone of the Main ridge		Northern slope of the axial zone	
		Formation	Abs. age in mln. yrs.	Formation	Abs. age in mln. yrs.
Tr-Q	Cenozoic	1. Formation of andesite and dacite of Elbrus.	-	1. Extrusions of granodiorite pophyry. (Tepli, Kalko). Trachyte formation of West Caucasus.	30
-Cr	Mesozoic	1. Possible small intrusions of anorthoclase granites.	-	1. Extrusive formation of granitoids (Indyuk, etc.).	About 70-100
C_1-P	Upper Paleozoic	1. Formation of gray granite: pegmatite, aplite, and granodiorite of the southern subzone.	200	1. Granitization of substrata from crystalline rocks of Urushten complex.	Bi-190
		2. Formations of M1 granites of the main ridge: pegmatite, aplite, alaskite, granodiorite, diorite.	200		
CmS-D_1	Urushten magmatic complex	Urushten complex (undivided), remnants of upper Paleozoic intrusions.	-	Formation of gneiss Na-granites: (a) pegmatite, aplite, (b) alaskite, (c) spessartite, (d) plagiogranito-gneiss	>230 >230
				Formation of ultrabasic rocks and gabbro-amphibolites (metamorphic).	

TABLE 2. Caledonian granitoids of the Urushten magmatic complex, 300-350 million years old (in percent by weight).

Components	Massive rocks			Mineral fraction with specific weight greater than 2.8		
	Plagio-granites		Plagio-alaskites	Plagio-granites	Plagio-alaskites	
	№ 94/55	№ 47/55	№ 221/55	№ 47/55	№ 219,55	№ 221/55
SiO_2	71,60	66,08	75,66	—	—	—
K_2O	0,49	1,20	0,18	—	—	—
Na_2O	4,77	4,78	5,48	—	—	—
$Ra-10^{-10}$	0,9	0,9	1,7	18	75	118
* $Th-10^{-4}$	9	9	16	140	900	1800
** $U-10^{-4}$	2,6	2,6	5	53	220	350
n	93	85	97	—	—	—
r	78	78	80	72	80	83

*In these and following analyses the determination of ThX was expressed in Th units.
**In these and following analyses the amounts of uranium were calculated from the equivalent weights of thorium and uranium.

NOTE: Comma represents decimal point.

TABLE 3. Upper Paleozoic granitoids of the deep facies of the main ridge complex, 200 million years old (in percent by weight).

Components	Microcline alaskite	Microcline-porphyrite granite	Bi-micaceous granite
	№ 57/39	№ 70/55	№ 320/50
Ra 10^{-10}	1,5 K_2O= 3,65	1,5 K_2O= 4,92	1,2 K_2O= 3,41
Th 10^{-4}	7 Na_2O= 3,14	8 Na_2O= 2,93	13 Na_2O= 3,37
U 10^{-4}	5 SiO_2= 71,65	5 SiO_2=77,37	3,5 SiO_2 =70,26
n	57	48	56
r	58	61	78

TABLE 4. Small intrusions of hypabyssal facies of the upper Paleozoic era, 180-200 million years old (in percent by weight).

Components	Massive rocks				
	Diorite	Granodiorite	Porphyry-granite	Granodiorite	Alaskite
	№ 88/55	№ 76/55	№ 128/55	№ 409/50	№ 30/50
SiO_2	56,02	68,13	75,60	61,24	77,02
K_2O	2,38	4,38	4,74	4,20	3,64
Na_2O	3,79	3,60	3,42	2,79	3,68
Ra 10^{-10}	1,0	2,0	3,3	260	200
Th 10^{-4}	21	14	20	76	280
U 10^{-4}	3	6	10	760	600
n	71	55	52	50	60
r	87	70	66	9	32

TABLE 5. Post-Lower Jurassic-Mesozoic complex of rocks, 110-120 million years old (in percent by weight).

Components	Massive rocks					Mineral fraction
	Dikes	Diabase	andesite	granite	granite	Granite:non-magnetic fraction with specific weight greater than 2.8
	№ 179/56	№ 481/56	№ 145/55	№ 178/55	№ 182/55	
SiO_2	48,07	47,60	60,06	71,25	70,10	—
K_2O	0,63	1,34	1,96	3,43	4,37	—
Na_2O	3,40	5,12	3,50	3,40	3,35	—
Ra 10^{-10}	0,5	0,5	0,5	3,0	1,0	83,0
Th 10^{-4}	8	8	7	18	15	3500
U 10^{-4}	1,5	1,5	1,5	9	3	240
n	90	86	80	61	53	—
r	84	84	85	70	83	93

NOTE: Comma represents decimal point.

TABLE 6. Cenozoic complex of intrusions and extrusions, 70-50 million years old (in percent by weight).

Components	Massive rocks					Mineral fraction greater than 2.8
	Granodiorite of the extrusive facies of the Indyuk Mountain			Granite	Granitoid veins	Granite
	№ 20/55	№ 295/55	№ 175/55	№ 207/54	№ 342/56	№ 207/54
SiO_2	Not determined	69,54	68,08	71,36	68,08	—
K_2O	"	2,75	3,68	4,37	4,43	—
Na_2O	"	3,56	3,31	3,28	3,72	—
Ra 10^{-10}	1,6	1,2	1,3	2,7	2,7	730
Th 10^{-4}	9	10	13	23	13	2400
U 10^{-4}	5	3	4	8	8	2120
n		65	58	53	56	—
r	65	76	76	74	61	53

TABLE 7. Tertiary extrusions and effusives, about 30 million years old (in percent by weight).

Components	Massive rocks					Mineral fraction greater than 2.8	
	Leucocratic granosyenites		trachytes			grano-syenites	trachytes
	№ 501	№ 308	№ 118/56	№ 394/56	№ 373/56	№ 561/54	№ 118/55
SiO_2	68,00	68,53	Not determined	66,35	68,3	—	—
K_2O	5,40	5,46	"	4,80	5,41	—	—
Na_2O	4,00	4,01	"	3,60	5,32	—	—
Ra 10^{-10}	6,5	8,0	2,5	1,3	1,1	24,0	58,0
Th 10^{-4}	13	30	16	14	13	110	130
U 10^{-4}	19	24	7,4	4	3	70	170
n	56	53		53	60	—	—
r	41	55	70	77	81	61	43

However, it should be mentioned, that these rocks contain carburan from the pegmatitic stage of formation of the intrusions, by interaction of granitic magma with rocks containing organic substances. The concentration of carbon compounds of uranium in parts of intrusive bodies, can satisfactorily be explained by the mobility of such compounds. It is also necessary to bear in mind the insufficiency of our knowledge of radioactive element migration in connection with the complexity (multistages) of formation of granite intrusions. In particular, there is so far no data on the influx, or conversely, outflow of radioactive elements during, for example, the process of alkaline metasomatism.

The radioactivity mainly due to thorium of Mesozoic microcline granite (specimen No. 182/55, table 5) is the known contradiction of the rule that the ratio of uranium to thorium increases with the increasing potassium content of granite. This is particularly noticeable in the mineral fraction with a specific weight greater than 2.8. It is important to mention that the geologic condition of the Mesozoic intrusion considered makes it possible to assume that its origin was complex, and that the enclosing rocks of the Lower Paleozoic magmatic complex (sodium granites of the first type!) had a considerable effect on its composition. It is characteristic that biotite in the granites No. 182 and No. 178 is almost unchanged, and the microcline of the granite No. 182 has metasomatic origin.

The relationship between the radioactivity of intrusive rocks close to the surface and the radioactivity of effusives connected with them, deserves attention. In particular, the intrusions of subalkaline rocks of post-Miocene origin, close to the surface, are rich in radioactive elements, particularly uranium (table 7), while effusive trachytes connected with them are considerably less radioactive, and contain more thorium than uranium.

Unusually interesting is the fact that liparite tuffs, or more correctly upper Tertiary ignimbrites (or perhaps younger) are strongly radioactive both when they appear as thick blankets covering watersheds or as "intrusive" bodies not reaching the surface. Their uranium and thorium content is greater than that of acid effusives. In the heavy mineral fraction (constituting only a small part of the rock) the uranium content increases 300 times, and thorium content nearly 350 times as compared with the content of these elements in the massive rocks. There is more thorium than uranium in both the heavy mineral fractions and in the massive rocks.

Table 9 is of interest when considering radioactivity of Upper Tertiary ignimbrite formations.

The table reflects the sharp increase of the total amount of radioactive elements in the magmatic fractions of effusives of the Upper Tertiary period, which is up to 70 times greater than that of magnetite from Paleozoic diorite. The ratio of thorium to uranium in the magnetites from effusives is much greater than in magnetite of Upper Paleozoic diorite. Magnetite from Elbrus andesite, which are of about the same age as the first effusives, is more than 4 times richer in radioactive elements than the magnetite of upper Paleozoic diorite but about 14 times poorer than the magnetite of liparite.

Due to the lack of data no explanation of these differences can be attempted. It is necessary in the future to compare the content of radioactive elements of rocks of the same petrographic type in various places, and in magnetite from rocks of different petrographic composition, but accompanying the same massif.

Table 5 gives data on the radioactivity of sodium type spessartite dikes. According to the current geologic theories, the magma from which these dikes originated arrived from considerable depths in the Earth's crust. Analyses indicate that the rocks of these dikes are the least radioactive, and contain much more thorium than uranium.

The present preliminary data on the distribution of radioactive elements in rocks of magmatic complexes of various ages in the North Caucasus indicate that this distribution does not follow any simple order. The complexity of the development of magmatic processes during the interaction of magma with the enclosing rocks is responsible for the many factors affecting the concentration of radioactive elements in rocks.

On the basis of our data we deduced mean figures representing the content of radioactive elements in intrusive rocks of the North Caucasus, containing 70±2% silicic acid, i.e., in rocks of the granitoid group, for magmatic complexes of various ages. We used these data for plotting the graph (fig. 1), in which the granitoid rocks of various ages in the North Caucasus are correlated with: (a) total content of uranium and thorium; (b) ratio of thorium to uranium + thorium, expressed in percent ("r"); (c) ratio of sodium to sodium + potassium expressed in percent ("n").

In the graph, the abscissas represent

TABLE 8. Upper Tertiary - Quaternary effusives and extrusions (in percent by weight).

Components	Massive rocks				Mineral fractions with specific weight greater than 2. 8; non-magnetic	
	Liparite lava	Liparite necks		Volcanic ash		
	№ 398	№ 351	№ 353	№ 87	№ 351	№ 353
O_2	Not determined	73,32	71,08	66,28	—	—
O	"	4,98	4,22	3,96	—	—
a_2O	"	3,64	2,80	3,17	—	—
10^{-10}	—	4,0	3,5	3,1	950	1000
10^{-4}	65	29	43	36	12300	15000
10^{-4}	20	12	10	10	2800	2900
n	—	52	50	55	—	—
r	76	71	81	78	81	83

E: Comma represents decimal point.

TABLE 9. Content of radioactive elements of some magnetites (in percent by weight).

Radioactive elements	Upper Paleozoic diorite, 200 million years old	Pliocene effusions No. 398	Necks		Elbrus andesites
			No. 351	No. 353	
Ra 10^{-10}	5,2	39,0	81	100	10
Th 10^{-4}	12	600	1800	2400	87
U 10^{-4}	15	110	230	290	29
r	44	84	88	88	75

TABLE 10. Mean content values of radioactive elements and alkali in granitoid rocks of magmatic complexes of various ages in the North Caucasus.

Magmatic complex and its absolute age	U	Th	U + Th	$K_2O + Na_2O$	SiO_2	r	n
	in n. 10^{-4} %			in % by weight			
I. Urushten (300 million years)	3.4	11.3	14.7	5.6	70	78	92
II. Granite complex of the Main fold 200 to 230 million years	4.5	9.3	13.8	7.1	73	68	54
III. Complex of small intrusions (200 million years)	8.0	17.0	25.0	8.0	71	68	54
IV. Mesozoic (?) (110 million years)							
a) basic rocks	1.5	8.0	9.5	5.20	48	84	88
b) acid intrusions	3.0	17.0	20.0	7.72	70	83	57
V. Tertiary complex							
a) acid intrusions (60 to 80 million years)	8.0	20.0	28.0	7.9	69	70	58
b) subalkaline effusives	3.5	13.5	17.0	9.5	67	79	57
c) subalkaline extrusions (30 million years)	21.5	21.5	43.0	9.7	68	79	58
VI. Upper Pliocene (Quaternary) complex: liparite, ignimbrite, etc.	11.0	36.0	47.0	7.8	72	76	51
Mean radioactive element content in acid rocks (according to A. P. Vinogradov)	3.5	18.0	21.5		--	--	--
Radioactive element content of basalts of oceanic islands (Jeffries)	2.6	4.6	7.2	--	--	--	--

the absolute ages of the granitoid rocks and the ordinates represent: (a) total content of radioactive elements Th + U; (b) values of the coefficients "r" and "n," taken from an arbitrary zero, which was fixed at r = 60 and n = 50, as compared with granitoids of corresponding age. The dotted line represents the mean content of uranium plus thorium ($21.5 \cdot 10^{-4}$%) in acid eruptive rocks, according to A.P. Vinogradov [6].

Analysis of the graph indicates that the total content of uranium plus thorium in eruptive granitoid rocks, from lower Paleozoic to upper Tertiary, has a fairly pronounced general tendency to increase. It should, however, be remembered that the Cenozoic group of rocks, for which this increase is particularly noticeable, is represented by extrusive facies, and facies which are relatively close to the surface. Further systematic investigation of the distribution of radioactive elements in rocks of various stages of formation of magmatic complexes at various depths is necessary.

As regards the comparison of the relative content of potassium and sodium on one hand and uranium and thorium on the other (coefficients "n" and "r") it appears that sodium rocks contain more thorium. Examples of such rocks are the granitoids (plagiogranites) of the Urushten magmatic complex, about 300 million years old. The[y] contain also basic and ultrabasic intrusions in the early stages of formation. The plagi[o]granites, 125 million years old, correspon[d]ing probably to the initial stage of the Meso[zoic]-Cenozoic magmatic activity are also predominantly of the sodium and thorium type. It was indicated above that microcline granites of the potassium type, formed by potassium replacement of the plagiogranite, have the same ratio of radioactive elements as the plagiogranites. It can be concluded, subject to further corroboration, that the enrichment in radioactive elements, particularly uranium, is not connected with the process of potassium metasomatism, which is one stage in the formation of granitoid intrusions.

The relatively small values of "n" and "r" for the Upper Paleozoic granitoid rocks indicate that potassium and uranium types of magma followed the formation of the granitoids in complexes characterizing the geosynclinal type of magmatic associations.

Miocene intrusions, close to the surface show the same tendency of decreasing "n" and "r" coefficients. However, the preserv[ed] rocks of effusive facies of Miocene magma[tic] activity and ignimbrite formations of the

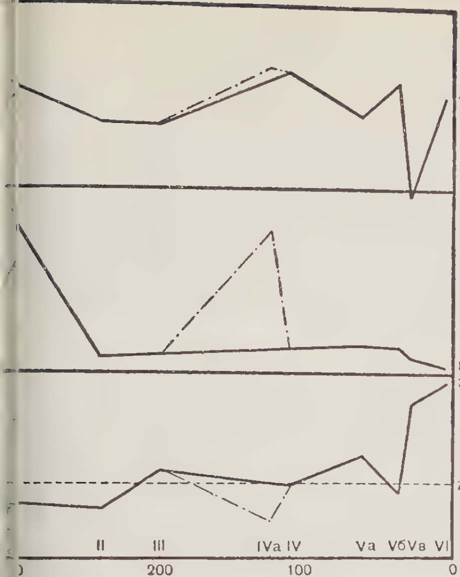

FIGURE 1. Averaged data characterizing the radioactivity and alkalinity of granitoid rocks (68-70% SiO_2) of complexes of various ages in North Caucasus.

$z'_1 - Z_2$ (continuous line - total content of U + Th in n.10^{-4}

$z_1 - Z_2$ (dotted line) - mean content of U + Th (of acid rocks according to A. P. Vinogradov); n_1-n_1 - value of "n" $\left(\frac{Na_2O}{Na_2O + K_2O}\right)$, $r_1 - r_1$ -- value of "r" $\left(\frac{Th}{Th + U}\right)$; I - VI - the number of the complex (see Table 10).

Tertiary period contain relatively more [th]rium, and relatively less sodium (as [co]mpared with potassium).

[I]solated figures regarding the radio[acti]vity of basic dikes of the initial stage of [Me]so-cenozoic magmatic activity indicated [tha]t: firstly, they are characterized by the [sma]llest total content of potassium and [tho]rium; secondly, the ratio of alkali ("n") [indi]cates, that they are of the sodium type; [thir]dly, the ratio of radioactive elements [("r]") indicates that they are of the thorium [typ]e. These properties of the basic rocks [are] clearly seen from the graph (fig. 1), [whe]re the points of the group IV-a are con[nec]ted by an interrupted line with the [nei]ghboring points corresponding to the acid [roc]ks. The shapes of the curves r1-r1 [(pa]rticularly) and n_1-n_1 for post-Lower [Pal]eozoic granitoid rocks are more even.

Resuming the discussion on the distribu[tio]n of radioactive elements in eruptive [roc]ks of various age complexes in the North Caucasus it is possible to give the following preliminary idea of the factors, which to a considerable degree determine the distribution of radioactive elements in magmatic rocks of the single structural-geologic region. The principal factors are: (1) the type of the magmatic association; (2) petrochemical character of magmas and the rocks crystallizing from them; (3) geologic conditions transforming the magmas into rocks; (4) the effect of the enclosing medium on the radioactive element enrichment of the magma during emplacement.

Fuller and more fundamental explanation of the causes of uneven radioactive element distribution in rocks requires the continuation of the work which we started on a much larger scale and for which we are giving here the preliminary conclusions. Such studies should include both the eruptive and the enclosing sedimentary and metamorphic rocks.

In any case, the averaged data on radioactive elements in eruptive rocks (plutonic and volcanic) obscure the complexity of their distribution in rocks of magmatic complexes of various ages, various stages of formation, and belonging to various facies.

In this respect we must agree with E.S. Larsen and G. Phair [20], that fewer specimens taken from one province or intrusion are more important than the generalized averaged figures on the content of radioactive elements in rocks.

II. Some remarks on the importance of the investigation of radioactive element distribution in rocks for the study of the Earth's crust structure and volcanic processes.

The understanding of endogenous processes taking place in the Earth's crust, which primarily include the volcanic, and in general the magmatic processes, is closely connected with the progress of our understanding of the Earth's crust structure.

On the basis of geophysical data on the speed of longitudinal waves, eminent geophysicists and geologists support the hypothesis of the very non-uniform structure of continents and ocean bottoms. This non-uniformity is mainly due to the varying depth of the surface of the so-called Mohorovichich division with respect to the Earth's surface. Below this surface the speed of longitudinal waves exceeds 8 km/sec., and it is believed that the rocks forming this shell, having a density between 3.1 and 3.3, have a composition similar to that

of dunites. The thickness of the sial layer, consisting mainly of granite, reaches 30 to 40 km. in the continents (in the plains 25 km. and in mountainous regions up to 50 km. Under the oceans, on the basis of geophysical data, sial is practically absent.

In 1953, one of the present authors published a paper, in which he developed some aspects of this problem [2]. It is convenient to return to this subject in connection with the discussion of radioactive element distribution in magmatic complexes of the North Caucasus.

F. Birch in his paper on the heat from radioactivity remarks that so far there are no reliable data on the distribution of radioactive elements in various parts of the earth. According to him, recent measurements of oceanic thermal radiation indicate that it does not differ in magnitude from the continental thermal radiation. The Earth looses heat at an approximate rate of $1.2 \cdot 10^{-6}$ cal/cm^2 · sec. Accepting the fairly widespread belief, that there is no granite layer under the oceans, Birch assumes that the total amount of radioactive substances is approximately the same, but in the continents they are concentrated mainly in the crust, and under the ocean -- at a certain undetermined depth below the crust.

This leads to definite contradiction. All geochemical research indicates that ultrabasic and basic rocks are the least radioactive, and the bulk of the radioactive elements is probably contained in the Earth's sialic layer. The same magnitude of thermal radiation of the Earth, in both continental and oceanic regions, indicates that either the sub-oceanic "ultrabasics" contain thorium and uranium in quantities equal to those of granites, or the sialic layer, in spite of the apparently convincing interpretation of geophysical data, is present under the oceans.

It should be mentioned that the ideas on the "granitic" and "dunitic" layers are fairly arbitrary, as such ideas are based mainly on data from rate of penetration measurements by longitudinal waves in various parts of the Earth.

The thickness of the layer having a density of 2.75 to 2.9, i.e., diorite, in many islands of the Pacific Ocean is not less than 25 km. This can be seen on the section of the Pacific Ocean given in the article of P.N. Kropotkin [12]. In the region of Kyoto (Chonsu, Japan), according to Kishimoto [19], the substratum is found at the depth of 32 km., and in New Zealand -- at about 20 km. Consequently, the thickness of the sial layer having a density of 2.8-2.9, is of about the same order, for continental plains and some oceanic islands.

Much geologic data, given in G.D. Afanasyev's article in 1952 [2] indicate that the activity of oceanic volcanoes gives rise to rocks of granite composition from the interior, and also Meso-cenozoic sedimentary rocks. In the article by V.V. Belousov [6] are also given important facts, indicating relatively recent (Cenozoic) non-uniform sinking of the ocean bottoms, particularly the Pacific.

All the above indicates that one of the most important and interesting geologic problems, that of the origin and history of oceans, is far from solved. In particular, the systematic study of the geology of the ocean bottom by the Institute of Oceanology, Academy of Sciences, U.S.S.R., will probably have important significance. Not less important are the experimental studies on the physical properties of rocks, especially on the correct interpretation of the rock penetration rate by longitudinal waves under variable conditions. In this respect the paper by M.P. Volarovich [8] is of interest. He proves experimentally that a sharp increase of the speed of longitudinal waves (by 8 to 15 percent) is observed when the pressure is increased from 800 to 1,200 kg/cm^2.

A knowledge of the Earth's crust structure is necessary for the knowledge of the development of volcanic phenomena. The heat generated by fission of radioactive elements is one of the most probable sources of heat (we will not discuss the hypotheses regarding the original thermal state of the Earth), and the volcanic processes, contemporary, and of the recent past, are known to take place in the oceanic and continental parts of the Earth's surface.

In the present state of our knowledge it appears that magmatic foci, with which active volcanoes are connected, are situated at considerable depths. L.K. Greyton [10], studying such volcanoes as Paracutin and Kolimo, confirmed the data on the situation of volcanic foci at great depths. According to the data of G.S. Gorshkov, the magmatic focus of the Klynchevsk group of volcanoes is at a depth of about 60 km. [9].

The example of the North Caucasus folded region indicates, that acid members of the post-Proterozoic magmatic complexes of various ages contain about equal amounts (total thorium plus uranium) of radioactive elements. The known enrichment is characteristic predominantly for hypabyssal and effusive formations. We could not take into account the possible difference between the

sent-day amount of radioactive elements he rocks of old complexes and the original ount, due to the migration of radioactive nents and their fission products during the g geologic history of the North Caucasus.

ssuming that the observed radioactivity he youngest rocks is the closest to their ginal radioactivity, we will now discuss, n the examples of young rocks of the casus, the probability of considerable accumulation in rocks, due to radio- ve fission of uranium, thorium and potas- n.

.K. Greyton believes that the limited mal possibilities of radioactive substances, also the contradictions in relationships veen the known content of radioactive nents in rocks on the one hand, and vol- c phenomena on the other do not corro- ite the hypothesis of radioactive heating he local cause of volcanic activity.

. Daniels [17] estimates the approximate ibility of continuous evolution of heat by nium, thorium and other radioactive nents, which can cause periodic heating ndividual parts of the Earth's crust. He eves, that if part of the energy of a oactive process could somehow be stored ng a period of time, and then suddenly ased, a considerable amount of heat d be obtained. By the same method as describe below (but without considering ssium), F. Daniels calculated that dur- 20 million years a rock containing 10^{-3} ent uranium and $3 \cdot 10^{-3}$ percent thor- should emit 260 cal/g of heat. Such an unt of heat could raise the temperature he rock by 1,000 degrees and melt it. -- writes the author -- there are no esses during which all the energy is ed and suddenly released. However, he ioned that some minerals can accumu- up to 89 cals. of energy per 1 g. of ral, i.e., amounts of energy having ogic significance.

ccording to the data from Rankama, els and other work (cited above), the al amount of heat emitted by radioactive on of one gram of thorium is equal to 3 cals., and of uranium -- 0.75 cals. ulations given in Rankama's work indi- that each year in 1 g. of granite, aining 34,000 g. potassium, 13.5 g. um, 4 g. uranium, and 900 g. rubidium ton of rock, $6.71 \cdot 10^{-6}$ cals. of heat emitted due to the fission of these ele- s.

e calculated, analogously, the amount at evolved in 1 g. of rock, due to the on of uranium, thorium and potassium, Upper Tertiary acid effusives of the North Caucasus according to the content of these elements in the rocks (table 8). The amount obtained was equal to 10^{-5} cal. per gram of rock.

In addition to the radiochemical determination of uranium and thorium, we obtained much data by direct determination of uranium and also from measurements of the radioactivity of rocks with UR-4 counters. All these data indicate that the figures corresponding to the uranium, thorium and potassium content of the specimens (table 8) can be extrapolated to the entire bulk of liparite. Yu. P. Masurenkov [13] gives a fairly convincing concept of the mechanism of introduction of the volcanic rocks and estimates the total volume of the erupted volcanic material as 43 cubic kilometers, which is approximately equal to 100 billion tons.

Thus, it appears that large amounts of uranium and thorium are dispersed through all this volcanic mass, and under suitable conditions could represent a potent source of heat. Obviously, in this case, this heat was utilized as the enormous energy of a volcanic process, which was also the cause of the local complex dislocation of enclosing rocks. In connection with this, the data of L.K. Greyton [10] on the ratio of volumes of gas and melt on various levels of volcanic channels, for granite magma containing originally 9.4 percent dissolved volatile substances, are of interest. He concludes that the surface part of the channel is filled with a piston of foam.

The appearance of ignimbrite rocks, and in particular rocks forming neck-like extrusive bodies in the Nizhne-Chechen region (North Caucasus), obviously depends on the ratio of gas to melt during the time of the appearance of magma. The rocks forming the edges of the extrusive bodies are very porous, tuff-like, and have a specific weight of 1.08, while the central parts of these bodies are more dense. Since the theories on the anatectic origin of the granitoid magmatic masses of Paleozoic and more recent eras are very convincing, it was of interest to find out, in spite of the arguments by Greiton and other authors, whether there are reasons to believe that one of the necessary causes of heat accumulation in amounts capable to melt the shale type mass of aluminosilicic rocks is the heat due to radioactive fission of compounds found dispersed in the rocks.

Calculations indicated that due to the specific heat capacity of granitoid rocks, equal to 0.17 to 0.2, and the low heat conductivity of phyllites, equal to $6.77 \cdot 10^{-3}$ cm./g. sec. [12], the accumulation of heat due to radioactive fission, in an amount

sufficient to raise the temperature of the rocks to 900 degrees (centigrade) is possible. According to the experimental data of Tuttle and Bowen [22] these temperatures are higher than those at which, at corresponding pressures, the melting of granites begins. For the accumulation of this quantity of heat, including the latent heat of fusion of the order of 60 cals., 20 million years are needed in the case of the formation of a magmatic source at depths of the order of 60 km. For the contents of radioactive elements discussed above, equal to $4.5 \cdot 10^{-5}$ g./g., the accumulation of heat due to radioactive fission is not possible at depths less than 2 km. below the surface of the Earth, due to the loss of heat caused by conductivity of enclosing rocks. For the same reason, at a depth of 2 to 60 km. the rate of heat accumulation due to radioactivity will be greater for rocks situated deeper, which contain sufficient amounts of radioactive elements.

The probability of how important a part is played by radioactive processes in the formation of anatectic magmas, and recent volcanic phenomena, follows from the above calculations for liparite effusives of the upper Tertiary period in the North Caucasus. We did not consider the possible accumulation of energy due to changes in minerals, as we had no data on this subject.

The probability of the formation of magma at various depths, and the data on the distribution of radioactive elements in rocks (both eruptive and sedimentary), indicate that the phenomena of radioactive fission, together with the energy of tectonic and other processes contribute to the accumulation of heat in isolated parts of the Earth's crust. This heat is probably formed in amounts sufficient for melting of the sub-strata, i.e., for the formation of magmas.

The above data on radioactivity of rocks in the Caucasus indicate that one of the ways leading to the solution of this important geologic problem (the sources of the volcanic heat) is systematic study of the distribution of radioactive elements in rocks.

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Institute of Geology of Ore Deposits,
Petrography, Mineralogy and Geochemistry,
Academy of Sciences, U. S. S. R., Moscow

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GROSSULARITE-WILLASTONITE SKARNS OF THE EMEL'DZHAK PHLOGOPITE DEPOSIT (SOUTH YAKUTIA)

by

M. A. Litsarev

ABSTRACT

This paper presents the results of studies on grossularite-wollastonite skarns, which are unusual for the Archean complex of the Aldan massif. The geologic distribution of the skarns and their structure and mineral composition are discussed. A description of the minerals and their behavior in individual diffusive metasomatic zones is given.

The problem of extent and depth of the system is also discussed.

* * * * *

INTRODUCTION

Since 1952-1953, certain calcium minerals were identified in the Archean metamorphic complex of the Aldan crystalline massif, which were unusual for the typical mineral associations of the Aldan [5, 7]. These minerals are: grossularite, wollastonite, prehnite, datolite, vesivianite, and pumpellyite.

Since this paper is concerned with grossularite-wollastonite skarns, identified in the Vtoroy region of the Emel'dzhak phlogopite deposit (Aldan province, Yakut ASSR), it appears useful to review briefly the known data regarding grossularite, wollastonite and other minerals mentioned above.

All these minerals occur within the Archean metamorphic rocks, but their formation is due to processes of various ages. Thus grossularite from the skarnlike hedenbergite-grossularite rocks is considered by D.P. Serdyuchenko [15] to be the product of regional and contact injection metamorphism between alaskite granites and Archean siliceous, argillaceous and dolomitic rocks.

According to L.I. Shabynin (private communication), the appearance of prehnite and pumpellyite in the crystalline shales and gneisses of the Dess river basin is due to Proterozoic magmatism. The prehnite mineralization on the right bank of the Aldan River (located 1.2 km. below Grekovsky cataract in migmatized biotite-hornblende gneiss) was also determined to be Proterozoic by Shabynin. Prehnite from the Emel-dzhak phlogopite formation was described in detail by V.A. Galyuk [2], who related it to the activity of more recent hydrothermal processes.

Vesuvianite from the contact zone between Archean calcareous rocks and the post-Jurassic syenite-porphyry dike (Tayezhnoye iron ore-phlogopite deposit in the Aldan region) was correlated with post-Jurassic formations by L.I. Shabynin (the vesuvianite replaced the syenite-porphyry). Datolite, identified in calcareous rocks near the middle reaches of the Kuranakh River [14] is also related to the post-Jurassic hypabyssal intrusive complex.

Wollastonite and grossularite, widely distributed in the middle reaches of the Emel-dzhak River (in the plain of the phlogopite deposit by the same name [13]), are of great interest. Gneissic wollastonite rocks, accompanied by hysterogenic grossularite ($N = 1.760 \pm 0.003$) and prehnite,[1] were found here in continuous deposits extending over several hundred meters. These rocks were conformable with the surrounding diopside and diopside-scapolite rocks, with diopside-feldspar and other crystalline shale

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[1] In our paper (Doklady, Akademiya Nauk SSSR t. 108, no. 1, 1956) grossularite and prehnite are not mentioned. These minerals were found after the paper was sent to the press.

and gneiss. In addition to the Archean granites and pegmatites, younger magmatic hypabyssal rocks were also found in this region. Their ages are not definite, due to the absence of sedimentary or metamorphic rocks younger than the Archean.

By convention they are included in the post-Jurassic hypabyssal complex of analogous regions in the Aldan massif, although according to N.F. Klekovkin and G.S. Gorshkov [3], some of the intrusions are perhaps older (down to Proterozoic). However, we have insufficient data for determining the connection between the formation of wollastonite-grossularite-bearing rocks and the secondary, more recent metamorphism, which could be due to the post-Archean magmatism. It is most probable that these rocks were formed as the result of metamorphism of the original calcareous, argillaceous and siliceous sedimentary rocks, during the process of the general alteration of the Archean sedimentary system, under conditions of high temperature and great depths. L.I. Shabynin (private communication) reached some interesting conclusions on this subject. He discovered (2 km. below the mouth of the Eget River) analogous wollastonite-grossularite containing rocks, surrounded by a block of lime-silicate rocks of the Dzheltulin series, on the left bank of the river Timpton. It was found that the rocks were identical with the corresponding Emel'dzhak rocks as regards their succession, mineral composition, structural and textural properties.

L.I. Shabynin concluded from this data that rocks belonging to a transitional shallower facies are associated with the upper parts of the Aldan Archean system (upper Dzheltulin series), where the conditions were suitable for the formation of certain calcium minerals (wollastonite, grossularite). Obviously, the fact that the thickness of the metamorphic system in Aldan is about 22 km [17, 18], should be taken into account.

In addition to the regions mentioned above, we also discovered wollastonite in the Kuranakh phlogopite deposits. Here, however, it is found as isolated specimens, and its geologic position is not quite clear.

Grossularite-wollastonite skarns of the Vtoroy region of the Emel'dzhak phlogopite formation deserve particular attention. Since similar formations in the Archean Aldan massif were unknown, and have not been mentioned in the literature on the Aldan, the position of these skarns, the structure of the skarn zones, their mineral composition and the origin of minerals in these zones appear to be of interest.

A short geologic and petrographic description of the Vtoroy region.

The Vtoroy region is situated 4 km. southwest of the mining village of Emel'dzhak, on the right slope of the Vtoroy valley (left tributary of the Emel'dzhak river in its middle reaches), 0.4 km. from its mouth. The region is characterized by highly metamorphosed Archean rocks, intensely and linearly folded, represented by various crystalline shales and gneisses (pyroxene-amphibole, biotite, biotite-hornblende hypersthene, etc.), and also by diopside, spinel-diopside and phlogopite-diopside rocks, with interlayers and lenses of forsterite-spinel calcareous rocks and marbles. The general strike of strata is northwest, and metamorphic rocks are everywhere intruded by granite and pegmatite of Archean age. More recent post-Jurassic (?) magmatic rocks are absent. The nearest part of a small post-Jurassic (?) intrusion is situated, according to G.S. Gorshkov [3] 0.5 to 0.7 km. northeast of the region. In addition to the widely distributed magnesium skarns (diopside and phlogopite-diopside), lime skarns (grossularite-wollastonite) are found in the region, but they did not develop here very strongly. Since we are only interested in calcareous skarns, it is useful, before describing them, to review briefly the rocks directly involved in the formation of these skarns, i.e., pegmatites and marbles.

Pegmatites appear as irregular bodies, 5 to 7 m. thick; these rocks are light to dark gray, and coarsely granular. The size of the grains is usually 2 to 3 cm., but often up to 6 cm. The pegmatites are composed of microcline-perthite (Ng = 1.528 ± 0.003; Np = 1.522 ± 0.003; 2V = (-) $80 \pm 2^{\circ}$ angle Ng with $\perp$ 010 is 16°), quartz, monoclinic pyroxene (Ng = 1.715 ± 0.003; Np = 1.688 ± 0.003; 2V = (+) $60 \pm 2^{\circ}$; cNg = 42), and occasional grains of sphene and magnetite. The pegmatites have the usual structure, but the idiomorphism of monoclinic pyroxene with respect to potassium feldspar and quartz, usual for Aldan pegmatites, should be noted, as well as the characteristic mutual ingrowths of potassium feldspar grains along their contacts.

Marbles are found among forsterite-spinel, calcareous rocks or diopside, spinel-diopside and phlogopite-diopside rocks. They form small lenses 2 to 4 m. thick and 6 to 8 m. long. They are coarsely granular, white, consisting mainly of calcite (95 to 97 percent); the main impurities are small grains of diopside, scapolite and apatite. The size of the calcite grains is usually 0.5 to 0.8 cm., but in the contact zone with pegmatites an increase to up to 6 cm. and more is observed.

Finally, we should consider the problem of the position of the phlogopite horizon in the section of the Aldan Archean in the Emel'dzhak deposit (including the Vtoroy region). Up to the present time there is no generally accepted explanation of this subject. It is known that D.S. Korzhinskiy [6] separated the Aldan Archean into three groups (from bottom to top): Iyengren, Charnokitov, and Dzheltulin. On the basis of this division some writers place the productive phlogopite horizon in the upper parts of the Iyengren stratum, others [3] at the top of the Charnokitov bed. L.I. Shabynin and V.A. Galyuk [2] place the Emel'dzhak deposit in the Dzheltulin stratum. We agree with the last point of view, on the basis of the results of work of D.S. Korzhinskiy [6], who identified the Dzheltulin stratum not far from the deposit, farther down the river Bolshoy Vllymakh, and showed that the rocks of the Dzheltulin stratum are very widespread in that region, and that they extend to the region of the deposit. Analogous rocks, characteristic of the Dzheltulin stratum, developed also in the region of the deposit.

Grossularite-wollastonite skarns were found in the north and south parts of the Vtoroy region. They usually accompany the narrow contact zone of marbles with pegmatites. The thickness of the skarns is not great, and with the near-skarn rocks, does not exceed 0.5 to 0.6 m.[2] Small, isolated inclusions of wollastonite skarn in marbles, up to 15 cm. in size, are of great interest (see fig. 1). Such small inclusions usually consist only of wollastonite, which is often replaced by finely granular aggregate of calcite and quartz in fractures. In larger inclusions the central parts appear as a light gray or white rock of pegmatite composition. The outerparts, in addition to wollastonite contain scapolite and grossularite, developing from potassium feldspar.

The study on the metasomatic formations, distributed along the pegmatite marble contact, indicates that they are zoned. Only two zones are distinctly visible: pyroxene-scapolite accompanying pegmatite, and grossularite-wollastonite, which is in direct contact with the marble. The position of these zones are shown in fig. 1.

The study of numerous thin sections from transverse sections of the skarn at the marble and pegmatite contact made it possible to describe the structure of the zones and their mineral composition in more detail. The following order of the zones was determined (from pegmatite to marble):

1. Unchanged pegmatite. Mineral composition: potassium feldspar, quartz, monoclinic pyroxene, occasional grains of sphene and magnetite. The description of the rock was given above.

2. Near skarn rocks. Here belong pyroxene-plagioclase and pyroxene-scapolite rocks, situated between the unchanged pegmatite and the skarns. The transition from the pegmatite to the near-skarn rocks is usually sharp, and the change of the paragenesis is observed over 1 to 1.5 cm. In this case potassium feldspar, quartz and magnetite disappear completely from the pegmatite, while plagioclase appears, and the amount of monoclinic pyroxene and sphene increases. The thin sections clearly show the replacement of potassium feldspar by plagioclase; it begins usually in the outer parts of the grains and develops toward the center. Plagioclase often appears at the contact of the pyroxene and potassium feldspar grains; small amounts of plagioclase appear around the pyroxene grains and spread toward the potash feldspar, until it is completely replaced. The result is the formation of a zone of pyroxene-plagioclase rocks, consisting of plagioclase (85 to 90 percent), monoclinic pyroxene (10 to 14 percent) and accessory sphene. The rock is medium granular, the usual size of the grains being 1 to 2 mm. The limit of pegmatite replacement is irregular, which indicates possible fractures, or non-uniform porosity of the replaced rock. The thickness of the pyroxene-plagioclase zone is small and does not exceed 1.5 to 2.0 cm. Sometimes this zone is completely absent, and the unchanged pegmatite is in contact with the pyroxene-scapolite rock. The latter is formed in two ways: it either replaces the pyroxene-plagioclase rock (when it is present) or it develops directly on the pegmatite. In the first case the change of the mineral composition consists only of the replacement of plagioclase by scapolite. The transition from pyroxene-plagioclase rock to pyroxene-scapolite is sharp. When scapolite replaces the unchanged pegmatite, it develops on potash feldspar, the remnants of which are often observed in large grains of scapolite.

The zone of pyroxene-scapolite rock extends over the whole skarn belt (fig. 1). It is characterized by light, to white, color and granular structure, with the size of the grains being 1 to 2 mm. The rock thickness varies from 1.5 cm. to 0.5 m. Pyroxene-scapolite rock can be modified by development of younger prehnite on the scapolite. Near the skarns grossularite appears, which replaces both scapolite and pyroxene.

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[2] The expression: "near-skarn rocks," "endoskarns" and "exoskarns" are used according to the definitions by D. S. Korzhinskiy 9, 11 .

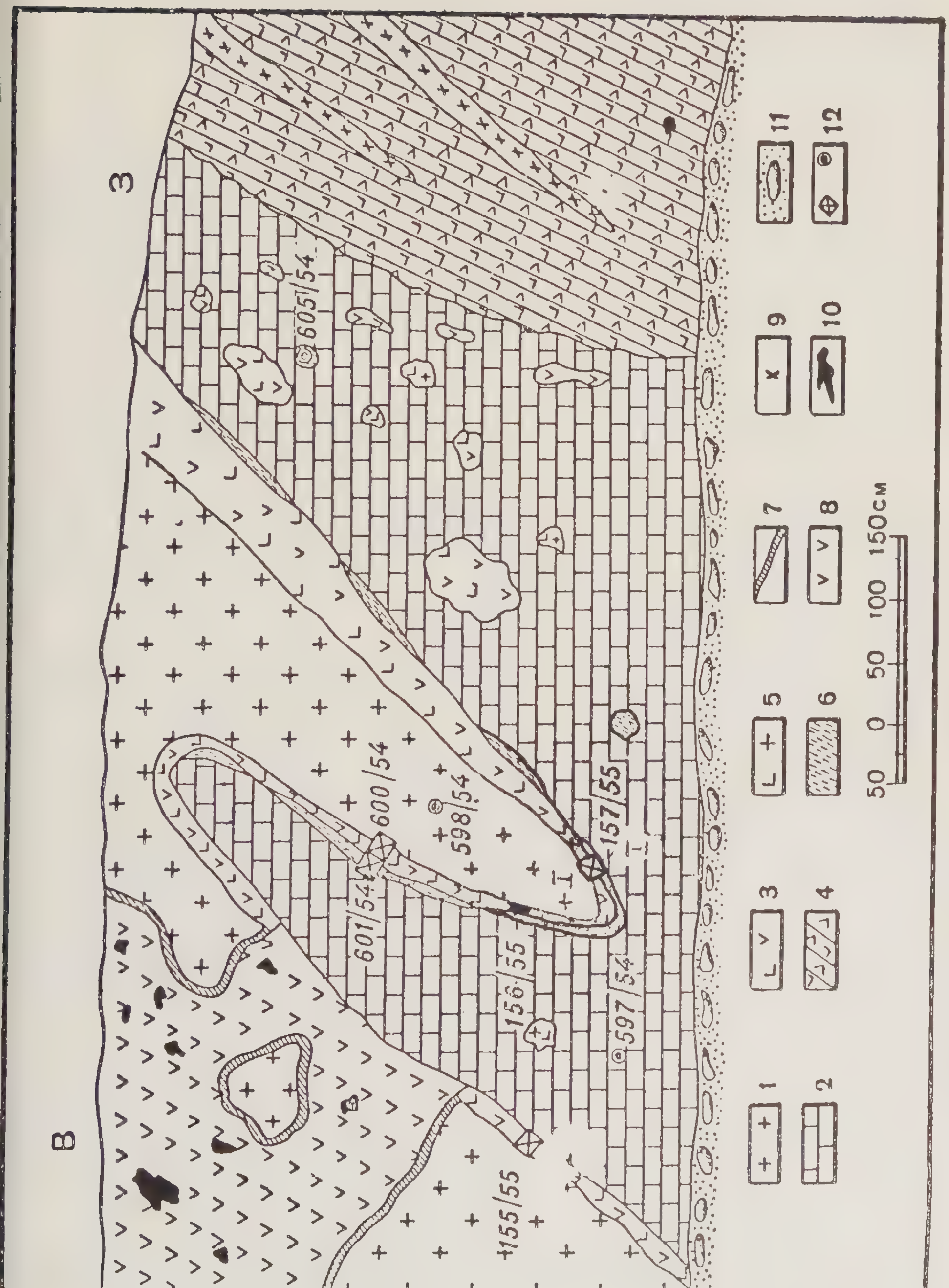


FIGURE 1. Sketch of the South Bench Wall, 2nd Southern Pit, Region Vtoroy Region, Emel'dzhak Phlogopite Deposit.

1 - pegmatite, 2 - marble, 3 - near-skarn pyroxene-scapolite rock, 4 - reticulate pyroxene-scapolite shale, 5 - scapolite-pegmatite, 6 - grossularite-wollastonite skarn, 7 - scapolite-diopside zone of pegmatite replacement, 8 - diopside rock, 9 - granite, 10 - calcite-phlogopite nests, 11 - dump, 12 - places from which samples were taken and their numbers.

3. Grossularite-wollastonite skarns. Near-skarn rocks sharply pass into grossularite-wollastonite skarns, which are situated between the near-skarn rocks and marbles. The thickness of the skarns is usually 5 to 8 cm., but sometimes reaches 14 cm. The skarn zone is often absent (fig. 1) and in such cases marbles are in direct contact with the near-skarn pyroxene-scapolite rocks. The skarns are white, and have granular structure; the sizes of the grains vary from 1 to 3 cm. The composition of the skarns changes considerably in the parts close to the marbles. This is best seen by comparing the skarns which are far removed from marbles with those which are in contact with them. The former, in addition to wollastonite (70 to 80 percent) contain scapolite (10 to 15 percent), monoclinic pyroxene (6 to 10 percent), garnet (3 to 5 percent), and small amounts of calcite and sphene. As the marbles are approached, sphene and scapolite disappear, the amount of pyroxene decreases considerably, and the wollastonite content increases to 95 to 97 percent.

The change in composition of the skarns is probably due to the fact that the growth of the grossularite-wollastonite zone involved the replacement of not only pegmatite but also marble. The inner parts of the skarns, close to the pyroxene-scapolite near-skarn rock, containing in addition to wollastonite considerable amounts of scapolite and sphene, were formed by the replacement of near-skarn rocks, with the formation of endoskarns. This also follows from the fact that the appearance of scapolite is accompanied, according to thin section study, by the disappearance of plagioclase or potash feldspar, which form a part of the silicate rock. On the other hand, the presence of sphene is characteristic of endoskarns, in which they differ from exoskarns, as repeatedly stated by D.S. Korzhinskiy [9, 11]. The skarns in direct contact with marble, consisting almost exclusively of wollastonite, with total absence of sphene, were probably formed by replacement of marble, and should be considered as exoskarn. Consequently, the contact between endo- and exoskarns (i.e., the original contact between pegmatite and marble) should coincide with the zone of disappearance of sphene and scapolite. The diagram (fig. 2) represents this contact in simplified form.

4. Calcite marble. Mineral composition: mainly calcite and small amounts of monoclinic pyroxene, scapolite and apatite. The description of the marble was given above.

Thus, the following zonation was determined:

1. Unchanged pegmatite.

2. Near-skarn rocks:

   a) pyroxene-plagioclase
   b) pyroxene scapolite

3. Grossularite-wollastonite skarns:

   a) endoskarns
   b) exoskarns

4. Calcite marble.

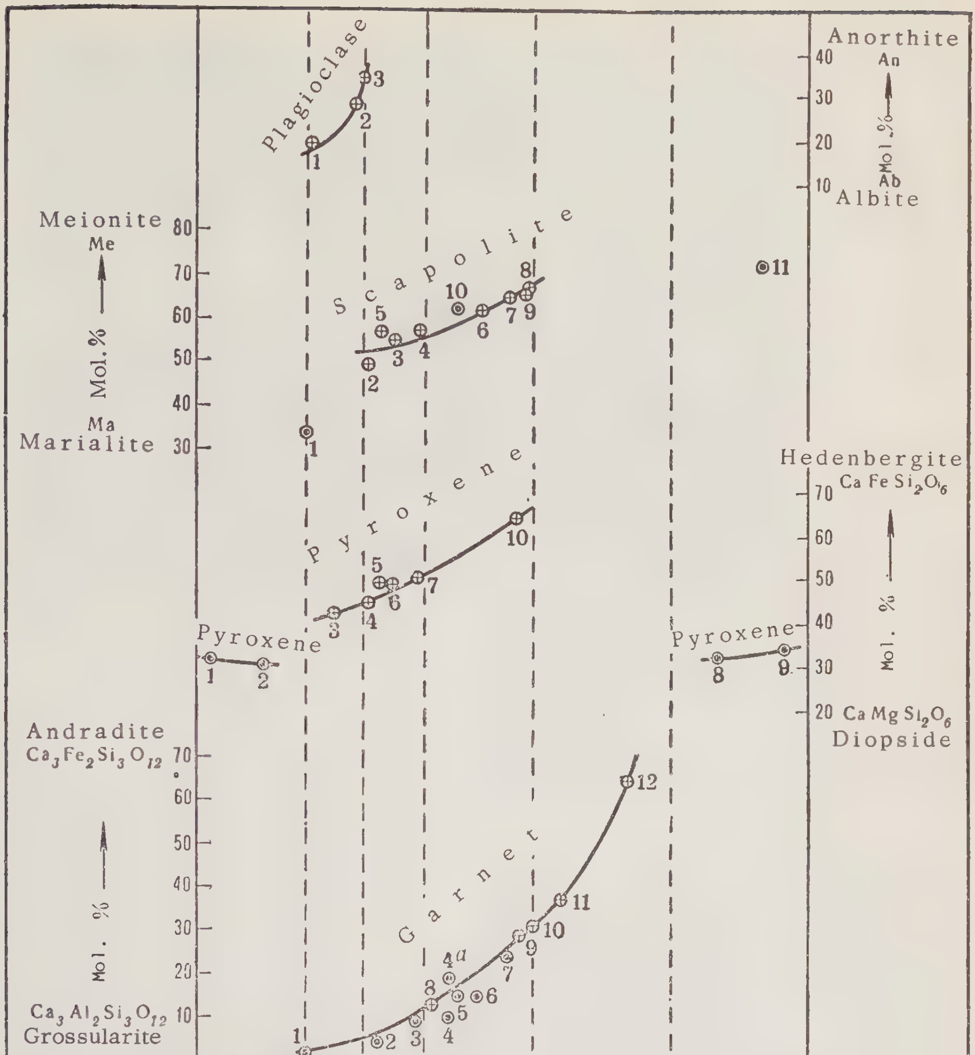
The relative thickness of the separated zones is very variable. It is enough to say that in some skarn sections, the thickness of grossularite-wollastonite skarns is greater than the thickness of the near-skarn rocks (see fig. 2); in other cases the section shows absence of skarns, while the thickness of the near-skarn rocks reaches 0.6 m.

Description of minerals of calcareous skarns and near-skarn rocks

The principal minerals in the skarns and near-skarns studied are plagioclase, scapolite, monoclinic pyroxene, wollastonite and garnet; of the lower temperature formations, only prehnite is of interest, and will be discussed here.

Plagioclase always accompanies the pyroxene-plagioclase zone of near-skarn rock, of which it is the main constituent (85 to 90 percent of the rock volume). As was stated above, plagioclase develops from potash feldspar, which it replaces, forming 0.8 to 1.0 mm. tablets with typical polysynthetic twinning. It was found that the composition of plagioclase, even within the limits of thin pyroxene-plagioclase rock zones (1.5 to 2.0 cm.), changes (in the direction of marble) from plagioclase no. 20 to andesite no. 35. The results of the measurements are given in table 1, and the data were plotted on the diagram representing the change of the mineral composition (fig. 2).

The diagram was constructed using the composition of various minerals as shown in tables 1, 2, 3 and 4. The zones and their mineral compositions, shown on the diagram, were determined by studying numerous thin sections. The thickness of the zones was determined by examining larger sections (Nos. 157/55, 157a/55) prepared from samples taken from cross section I-I (see fig. 1). The sections were prepared without cover glasses which made it possible to take mineral grains for the determination of refractive indexes from any part of each zone. Therefore, each point on the diagram corresponds not only to the composition of the mineral, but also to its actual position in



Thickness of Zones	---	13	14	25	32	---
Mineralogic Composition of Zones	Pf, Qu, Pyr, Sph, Mag.	Pl, Pyr, Sph.	Sc, Pyr, Sph, Gar.	Wol, Sc, Pyr, Gar, Cal, Sph.	Wol, Gar, Pyr, Cal,	Cal, Pyr Sc, Ap.
Name of Zones	Un-Altered Peg-matite	Pyr. Pl.	Pyr. Pl.	Endo-skarn	Exo-skarn	Calcite Marble
		Near-Skarn Rocks		Grossularite-Wollastonite Rocks		

FIGURE 2. Alteration diagram of plagioclase, scapolite, pyroxene and garnet, as a function of their location in the zone of contact-reaction metasomatism.

Crosses in circles denote minerals whose composition was determined from their optical properties, in thin sections, from cross-section I-I (fig. 1). Dots in circles denote minerals identified in thin sections and specimens not taken from the cross-section I-I. PF - potash feldspar; Qu - quartz; Pyr. - monoclinic pyroxene; Pl - plagioclase, Sc - scapolite; Wol - wollastonite; Gar. - garnet; Cal - calcite; Ap - apatite; Sph - sphene, Mag. - magnetite.

TABLE 1.

No. of measurement	No. of section	Place from which mineral was taken for measurement	Refractive indexes		Angle of extinction (010) for PM	Composition of plagioclase [1]
			Ng	Np		
1	157/55	Inner part of pyroxene-plagioclase rock zone	1.547	1.538	--	Oligoclase No. 20
2	157/55	Outer part of pyroxene-plagioclase rock zone	1.552	1.544	--	Oligoclase No. 29
3	157a/55	Contact of pyroxene-plagioclase and pyroxene-scapolite rocks	1.555	1.547	17°	Andesite No. 35

the section of the given zone. The numbers of the points representing the compositions of the minerals on the diagram correspond to the numbers of the individual measurements, given in the tables. It should be mentioned, that the composition of some minerals was also determined from samples from other sections, where the zone thickness was not the same as in cross-section I-I. In such cases the compositions were plotted on the diagram within the limits of corresponding zones somewhat arbitrarily, and therefore they are represented by a special symbol.

Scapolite. This mineral is more common than plagioclase. It is found in the near-skarn, pyroxene-scapolite rock, in grossularite-wollastonite endoskarn and in calcite marbles. In the near-skarn rock the scapolite is the main mineral, constituting up to 85 percent of the volume of the rock, and is present in the usual association with monoclinic pyroxene and sphene. Here, its formation is related to the replacement of either potash feldspar (in pegmatite) or plagioclase (in pyroxene-plagioclase rock). In the first case, fairly large (0.8 to 1.2 cm.) and irregular grains of scapolite are formed, often together with round remnants of potash feldspar (fig. 3). Sometimes finely granular scapolite develops along the contact between potash feldspar and calcite, as shown in figure 4. Scapolite formed by replacement of plagioclase appears usually as regular, polygonal grains, of about 1.0 to 1.5 mm. In grossularite-wollastonite endoskarn its appearance is identical. In calcite marble, scapolite is rare; sometimes it has regular structure, but more often it forms round grains of about 0.5 to 1.0 mm. Refractive indexes of scapolite (see table 2) are not constant and depend on the position of the mineral in the section of the skarn zone. The limits between which the refractive indexes can vary are fairly large: N_o=1.558 to 1.585, N_e=1.554 to 1.557. It was proved that the composition of scapolite changes not only when passing from one zone to another, but also within the limits of the same zone (see table 2, and diagram, fig. 2). For example in near-skarn, pyroxene-scapolite rock, the composition of scapolite changes from $Ma_{50}Me_{50}$ to $Ma_{43}Me_{57}$; in the zone of grossularite-wollastonite endoskarn, further increases in the meionite molecule content to 67 percent takes place. Observations indicate that the most acid scapolite, having the composition $Ma_{66}Me_{34}$ is formed by the replacement of potash feldspar; scapolite from calcite marbles has the most basic composition ($Ma_{28}Me_{72}$).

The relationship between plagioclase and scapolite in near-skarn rocks is of interest. It was stated above that plagioclase is completely replaced by scapolite. The composition of this scapolite is always more basic than that of the plagioclase. Thus, plagioclase having the composition of andesine no. 35 is replaced by scapolite $Ma_{50}Me_{50}$. The relationships between scapolite and plagioclase were studied in detail by D.S. Korzhinskiy [8]. Garnet of grossularite-andradite composition, and prehnite, often develops on scapolite of endoskarn and pyroxene-scapolite rock.

Monoclinic pyroxene is present in all the zones of the skarn belt, including unchanged pegmatite and calcite marble, but it does not occur in very considerable quantities. In near-skarn rocks and in the endoskarn, the pyroxene content reaches 10 to 14 percent, in pegmatites 5 percent and in exoskarn and marbles it is present as an insignificant impurity. Size of grains is 0.5 to 1.5 mm., or in pegmatites, up to 2.3 cm. The shape is usually round, but in marbles, in addition to oval or spherical grains, well formed crystals are often found. It should

FIGURE 3. Replacement of potash feldspar by scapolite. Visible round remains of potash feldspar by scapolite.

Section 577-a/54; enlargement 46, crossed Nicols; 1 - potash feldspar; 2 - scapolite; 3 - monoclinic pyroxene.

e mentioned that sometimes more recent yroxene is found in endoskarn, which is fferent from that described above. It is ound between the grains of wollastonite, capolite and the older pyroxene, and has ongated, irregular shape. The relationship the recent pyroxene with these minerals the endoskarn indicates that it was probbly formed together with garnet, which is so situated between the grains of the above inerals. In bulk, pyroxene is dark green, it in thin sections it has a characteristic ght green color. Pleochroism is absent. he results of the optical property determinaon of first generation pyroxene are given in ble 3. Comparison of the compositions of roxene from various parts of the skarn elt section indicates that the composition anges within the limits of the zone. For ample, in the pyroxene-scapolite rock ne (see fig. 2) the hedenbergite molecule ntent in the composition of pyroxene creases from 45 percent (point 4) to 52 rcent (point 7). The compositions of roxene from pegmatite and marble are milar (see diagram). They contain up to percent of the hedenbergite molecule, ich is not usual for pyroxene from mare. As a rule in Archean marbles from the dan, pyroxene is less ferrous, and correonds to the composition of diopside, and not sahlite.

Wollastonite is the main mineral in the grossularite-wollastonite skarns, and constitutes from 70 to 97 percent of the rock volume. It is found together with scapolite, pyroxene, garnet and sphene. It is elongated along b-axis of grains, which are usually mm to 3 cm and more in size. The color is white, but in thin sections colorless. The refractive indexes (measured in immersion liquids) are: $Ng = 1.631 \pm 0.003$; $Np = 1.1617 \pm 0.003$; $2V = (-)\ 39^\circ \pm 2^\circ$. Wollastonite is often replaced by a finely granular aggregate composed of calcite plus quartz.

Garnet is found in grossularite-wollastonite skarns, in near-skarn, pyroxene-scapolite rock and in the direct replacement zone of the pegmatite, where it develops on potash feldspar. Garnet is a secondary mineral of skarns, and its quantity does not exceed 5 percent of the rock volume. It is of well defined character, and its relationship with other minerals, as well as its predominantly grossularite composition, deserve attention. There are no independent zones or large accumulations of garnet in rocks. It is found either as separate grains and small nests, or it forms rims around scapolite (fig. 5).

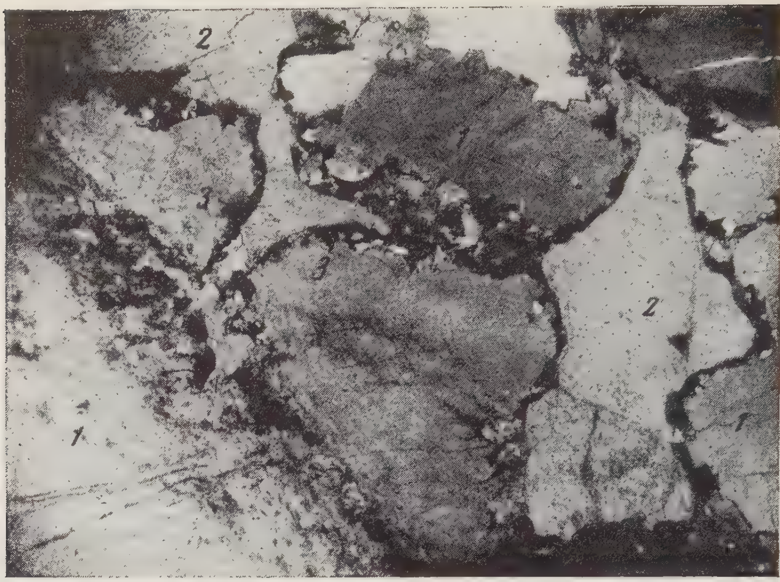


FIGURE 4. Formation of scapolite (dark rim) at the contact of grains of potash feldspar and calcite.

Section 604/54; enlargement 20; crossed Nicols. 1 - potash feldspar; 2 - calcite; 3 - scapolite.

The appearance of the individual, irregular grains of garnet and of small amounts of it in finely divided form is connected with the replacement of either potash feldspar in pegmatite, or of scapolite and pyroxene (of the first generation) in the near-skarn pyroxene-scapolite rock. Sometimes garnet develops along fractures in the wollastonite grains as thin chains. The garnet rims around scapolite are usually formed at the contact of scapolite with wollastonite, or more seldom with calcite. In both cases garnet replaces scapolite (partly or completely), and therefore the thickness of the garnet margins is not constant.

Scapolite is replaced not only by garnet, but also by quartz. Mean size of the garnet grains is 0.08 to 0.1 mm., and in rare cases up to 0.8 mm. Isotropic and anisotropic varieties of garnet were identified in sections. Anomalous garnet is biaxial, optically negative, has a small angle of optical axes; Ng - Np = 0.006 (measured with a Berek compensator); sometimes it exhibits indistinct sectorial extinction and zonal structure; interference color is gray. The relative ages of the varieties of garnet are not clear, and there are no bases for stating which one is older. Experimental investigation of the anomalous garnets of Tyrny-Auz, carried out by S.P. Solov'yev and Kh. S. Nikogosyan [16], indicated, that when heated to 756 to 860 degrees centigrade they pass into the isotropic state. Consequently, among the many causes of anomalous formation, temperature is an important one. Anomalous garnet is most often encountered in inner parts of the skarn belt, while the isotropic garnet is found in all its parts (endo- and exoskarn).

Numerous refractive index measurements of garnet (see table 4) indicate continuous change of its composition in the direction from pegmatite to marble (see fig. 2). Andradite molecule content increases gradually from almost pure grossularite, containing only 2 percent andradite (point 1, on fig. 2), to garnet with 64 percent andradite (point 12). One more detail should be mentioned: garnet closely resembling the grossularite in composition is formed mainly by replacement of potash feldspar. The more ferrous variety is related to the replacement of scapolite, wollastonite and pyroxene of the first generation.

Prehnite, the more recent low-temperature mineral, is found in the near-skarn, pyroxene-scapolite rock and in grossularite-wollastonite endoskarn. In all cases it is a secondary mineral, and develops on basic or neutral scapolite, grossular garnet and

TABLE 2.

No. of measurement	No. of section or specimen	Place from which mineral was taken for measurement	Refractive index N_o	Refractive index N_e	N_o-N_e	$\frac{N_o \quad N_e}{2}$	Composition of scapolite according to Sundius' diagram [19]
1	Section 156/55	Scapolite with remains of replaced potash feldspar	1.558	1.544	0.014	1.551	$Ma_{66}Me_{34}$
2	Section 157/55	Inner part of pyroxene-scapolite rock zone	1.570	1.549	0.021	1.5595	$Ma_{50}Me_{50}$
3	Section 157/55	Central part of pyroxene-scapolite rock zone	1.574	1.552	0.022	1.563	$Ma_{45}Me_{55}$
4	Section 157/55	Outer part of pyroxene-scapolite rock zone	1.576	1.552	0.024	1.564	$Ma_{43}Me_{57}$
5	Section 157/55	Inner part of pyroxene-scapolite rock zone	1.576	1.552	0.024	1.564	$Ma_{43}Me_{57}$
6	Section 157/55	Central part of grossularite-wollastonite endoskarn	1.578	1.553	0.025	1.5655	$Ma_{38}Me_{62}$
7	Section 157/55	Outer part of grossularite-wollastonite endoskarn zone	1.581	1.554	0.027	1.5675	$Ma_{35}Me_{65}$
8	Section 157/55	Outer part of grossularite-wollastonite endoskarn zone	1.583	1.555	0.028	1.569	$Ma_{33}Me_{67}$
9	Section 157/55	Outer part of grossularite-wollastonite endoskarn zone	1.582	1.555	0.027	1.5684	$Ma_{34}Me_{66}$
10	Specimen 600/54	Inner part of grossularite-wollastonite endoskarn zone	1.581	1.551	0.030	1.566	$Ma_{38}Me_{62}$
11	Section 575/54	Calcite marble	1.585	1.557	0.028	1.571	$Ma_{28}Me_{72}$

pyroxene. In addition to prehnite, calcite is always formed by replacement of grossularite. In sections, prehnite is colorless; it forms ray-like radial concretions, elongated tablets, and aggregates of flakes and tabular grains; it has good cleavage, the elongation is negative; 2V = (+) $67^o \pm 2^o$ refractive indexes: Ng = 1.644 $\pm$ 0.003, Np = 1.617 $\pm$ 0.003; the size of the grains is 0.02 to 1.0 mm. The formation of prehnite is due to replacement of high-temperature minerals and probably occurred in the last stages of skarn formation, under lower-temperature conditions.

Conclusions

1. The formation of skarns at the contact of Archean pegmatites with calcite marbles in the Vtoroy region of the Emel'dzhak phlogopite deposit took place in the post-magmatic stage, since the development of zones of varying composition is connected with the replacement of both marbles and pegmatites. The following zone order was established.

(a) unchanged pegmatite;
(b) near-skarn rocks:
  1) pyroxene-plagioclase, and
  2) pyroxene-scapolite,
(c) grossularite-wollastonite skarns;
  1) endoskarn,
  2) exoskarn,
(d) calcite marble.

TABLE 3.

No. of measurement	No. of section or Speci-	Place from which mineral was taken for measurement	Refractive indexes		2 V	cNg	Hedenbergite molecule content in mol. percent [1]
			Ng	Np			
1	Specimen 538/54	Pegmatite, 0.5 m. from zone of skarn formation.	1.717	1.690	--	--	32
2	Section 157/55	Pegmatite, 1 cm. from pyroxene-plagioclase rock.	1.715	1.688	60°	42°	31
3	Section 157/55	Central part of pyroxene-plagioclase zone.	1.723	1.698	--	45°	43
4	Section 157/55	Inner part of pyroxene-scapolite zone.	1.725	1.696	--	39°	45
5	Section 157/55	Central part of pyroxene-scapolite zone.	1.728	1.698	--	40°	49
6	Section 157/55	Central part of pyroxene-scapolite zone.	1.728	1.701	57°	42°	49
7	Section 157/55	Outer part of pyroxene-scapolite zone.	1.729	1.701	--	45°	51
8	Specimen 599/54	Marble.	1.717	.692	--	41°	32
9	Specimen 599/54	Marble.	1.719	1.687	--	40°	34
10	Section 157/55	Outer part of grossularite-wollastonite endoskarns zone.	1.737	1.708	--	--	64

2. The distribution of the zones in the section of the skarn belt, and the distribution of minerals constituting these zones (calcium aluminosilicates usually accompany near-skarn rocks and calcium metasilicates endo- and exoskarns), and also the change of mineral composition of within the zones, indicate that the zonal structure is due to bimetasomatic interaction between neighboring rocks, and is connected with mutual diffusion of components of these rocks. For example, the formation of grossularite or scapolite on potash feldspar of pegmatite, i.e., in the innermost part of the skarn zone, could only take place by migration of CaO from calcite marbles; on the other hand, the appearance of wollastonite exoskarn is obviously due to the transfer here of silica from pegmatite. Observations indicate, that the main components (Al_2O_3, SiO_2, CaO) of the skarn belt minerals were apparently brought in from outside by post-magmatic solutions; they were present here as components of neighboring rocks, and migrated only within the limits of the narrow skarn belt. This conclusion is corroborated by the round inclusions of wollastonite skarn, often containing grossularite, scapolite, monoclinic pyroxene and remains of rocks of pegmatite composition in the marbles. It is quite obvious that post-magmatic solutions, filtering through marble, did not carry with them the above components, as in such case the transformation of marble into skarn would be more pronounced. These solutions could cause only bimetasomatic interactions between inclusions of pegmatite composition and calcite marbles enclosing them. As a result, these inclusions were partly, or fully, replaced with the formation of wollastonite, scapolite, grossularite and monoclinic pyroxene.

FIGURE 5. Rims of garnet around scapolite at the contact of its grains with wollastonite.

Section 823/54; enlargement 20; no analyser.
1 - wollastonite; 2 - scapolite; 3 - garnet;
4 - monoclinic pyroxene.

The small thickness of the belt of skarn ormation (0.5 to 0.6 m.) indicates low ntensity of the skarn formation process.

3. Numerous measurements of refractive ndexes indicated that the compositions of arnet, monoclinic pyroxene, plagioclase, nd scapolite, gradually and continually hange, not only when passing from one zone o another, but also within the limits of one iffusion zone (fig. 2). These observations onfirm D.S. Korzhinskiy's [10] theoretical onclusions on the continuous change of the ineral composition in individual diffusive etasomatic zones.

4. The inspection of the relationships etween minerals indicates that they were ot formed at the same time, which was robably due to the change of temperature. here are three principal stages of minera- zation:

(a) in the first stage there were formed uch minerals as wollastonite, monoclinic yroxene of the first generation, plagioclase nd scapolite;

(b) in the second stage were formed: arnet (anomalous and isotropic) and mono- linic pyroxene of the second generation. arnet in all cases was developed after the minerals of the first stage and replaced them.

(c) in the third stage, characterized by the lowest temperature, prehnite was formed.

5. The fact that in thin sections the grains of wollastonite are very often in direct contact with scapolite indicates that paragenesis of wollastonite and scapolite is stable in the first stage of mineralization, i.e., under conditions of the highest temperatures. At lower temperatures, in the second stage of mineralization, the paragenesis of wollastonite and scapolite becomes unstable. Grossularite is formed as the result of reactions of these minerals with solutions forming rims around grains of scapolite, or completely replacing them. It should be concluded, that grossularite in this case is obviously the hysterogenic mineral, and should not be taken into account in solving the problem of deep facies of the system of rocks discussed. V.P. Kostyuk [12] was the first to doubt the existence of the deep facies of grossularite. He was working on paragenetic analysis of crystalline rocks of Podol'ye in the Vinnitsa region. It should be mentioned that D.S. Korzhinskiy [7], when isolating the grossularite facies, emphasized that he did not know examples of such facies. Our data indicate the non-existence of grossularite facies,

TABLE 4.

No. of measurement	No. of section or specimen	Place from which mineral was taken for measurement	Refractive indexes, N	Andradite molecule content in mol. percent [1]
1	Section 156/55	Area of replacement of potash feldspar by garnet.	1.738	2
2	Section 580a/54	Area of replacement of the near-skarn, pyroxene-scapolite rock. Garnet on scapolite in contact with calcite.	1.742	4
3	Section 580a/54	Area of replacement of the near-skarn, pyroxene-scapolite rock. Garnet on scapolite in contact with calcite.	1.750	10
4	Specimen 157/55	Garnet from finely divided sample of skarn.	1.750	10
4-a	Specimen 157/55	Garnet from finely divided sample of skarn.	1.767	10
5	Specimen 157/55	Garnet from finely divided sample of skarn.	1.759	15
6	Specimen 157/55	Garnet from finely divided sample of skarn.	1.760	16
7	Specimen 157/55	Garnet from finely divided sample of skarn.	1.774	24
8	Section 157/55	Inner part of endoskarn zone.	1.755	13
9	Section 157/55	Outer part of endoskarn zone.	1.781	29
10	Section 157/55	Outer part of endoskarn zone.	1.784	31
11	Section 157/55	Inner part of exoskarn zone.	1.796*	37
12	Section 157/55	Outer part of exoskarn zone.	1.837*	64

*Measured in phosphorous liquids; accuracy of measurement 0.003.

which was introduced by D.S. Korzhinskiy in 1940 [7]. In this case we are concerned with the first variant of Korzhinskiy's facies [4], from which the grossularite facies cannot be isolated.

6. The enormous thickness of the Aldan Archean metamorphic system (about 22 km.) in the vicinity of the Emel'dzhak phlogopite deposit, compared to the upper part of its section (Dzheltulin stratum), and the absence of connections between the formation of wollastonite, which is widely distributed here, with the secondary, more recent metamorphism indicate that the system of rocks constituting the region of the Emel'dzhak deposit was formed under conditions of shallower depth as compared with the wollastonite-free facies.

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Institute of Mining Geology,
Petrography, Mineralogy and Geochemistry,
Academy of Sciences, U.S.S.R., Moscow

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EXPLOSIVE BRECCIA DIKES OF TRANS-CARPATHIA

by

B. V. Merlich

ABSTRACT

In the paper there are described the breccia dikes of Trans-Carpathia, previously regarded as tectonic. Proof is given of their explosive origin. According to the latest review [1], explosive dikes are not described in our literature, and data on such formations can only be obtained from American sources [3].

Specific properties of explosive dikes are described, and the mechanism of formation of the dikes is outlined.

* * * * *

INTRODUCTION

In the Vyshkov region of Trans-Carpathia :here are steep breccia dikes, cutting erup- :ive and sedimentary-tuffaceous rocks. As :hese dikes contain ores, they were for nany decades the object of geological investi- gation, prospecting, and even exploitation. As a result, a large number of dikes were revealed by underground mining work, and studied in detail. Brecciated filling of the dikes, and their usual relation to linear structures, suggested to the majority of investigators that the dikes were formed by disintegration of rocks and their displace- ment during tectonic movements. However, the presence of characteristic properties places these dikes in the group of very unusual formations, the origin of which can- not be explained by tectonic, hydrothermal, or magmatic phenomena. This is why V.S. Sobolev and other authors [5], while suggest- ing that these breccias were formed as the result of movements of solidified or semi- solidified intrusions, admit that the problem of their formation is still not solved and requires further study [5].

In the summer of 1955 I studied the nature of these breccia dikes. As the result of observations in underground and open cast mines, and also microscopic and chemical study of the rocks, I concluded that the dikes are of volcanic, explosive origin.

Since, according to the latest, most comprehensive review of clastic dikes compiled by R.G. Goretskiy [1], there is no information on explosive dikes in our literature, and such formations are described only in the case of the Tintic region, Utah, U.S.A. [3, 8], I believe that it will be useful to describe the breccia dikes, and to give the data proving their explosive origin.

Brief geologic description of the region.

The Vyshkov region, containing the breccia dikes, is situated in the extreme southeast part of the Vygorlat-Gutin volcanic area, and consists of sedimentary-tuffaceous strata of Tortonian, Sarmatian and Pannonian rocks, intersected by numerous hypabyssal intrusions of quartz gabbro-diabase, granodiorite-porphyry diorite-porphyrite. The sedimentary-tuffaceous stratum is represented by argillite, sandstone and liparite tuff, and forms the rim of the northeast flank of a large synclinal fold, which is complicated by secondary folding. Intrusive massifs, corresponding to the facies of small intrusions, have irregular, round, and sometimes elongated shapes; their dimensions vary from 200 m. to 2 km. Granodiorite-porphyry is well crystallized and is composed of quartz, potash feldspar and acid plagioclase (oligoclase). The porphyry also contains labradorite, quartz, biotite and pseudo-flint. Analogous structural properties are also exhibited by diorite-porphyrite, but they are impreg-

nated with more basic plagioclase (bytownite) nypersthene, monoclinic pyroxene and strongly decomposed pseudo-flint. In the basic massif, plagioclase (oligoclase) predominates over potash feldspar and quartz. In granodiorite-porphyry and in diorite porphyrite numerous xenoliths of gabbro-diabase are observed.

Volcanic formations of the region are represented as follows: in effusive facies -- parts of dacite and andesite not yet destroyed by erosion; and in the subvolcanic facies -- by dikes of andasite-basalt and necks consisting of volcanic breccias, containing fragments of granodiorite-porphyry, diorite porphyrite, dacite, argillite, sandstone and tuffs cemented together by clay and tuffaceous material. Both sedimentary and eruptive rocks are cut by steep fractures, usually striking northeast. In some large fractures vertical dislocations of rocks caused terraced elevations of the region, and subsequent erosion removed the upper layers of sedimentary rocks, uncovering hypabyssal intrusions. The oldest eruptive rock of the region is gabbro-diabase belonging to the Lower Sarmatian. Later, in Lower Pannonian times, hypabyssal intrusions of granodiorite-porphyry and diorite porphyrite appeared and then, in the Upper Pannonian, volcanic activity began. This left andesite, dacite, and subvolcanic formations in the region.

Situation of breccia dikes.

The breccia of the dikes consists of various size fragments of granodiorite-porphyry, diorite porphyrite, gabbro-diabase, sedimentary rocks and tuffs, cemented by tuffaceous and sedimentary material.

The breccia dikes are most widely distributed in one of the largest intrusions of the region -- in the Vyshkov granodiorite-porphyry massif and in the enclosing sedimentary rocks consisting of argillite, and to a lesser degree of sandstone and tuffs. The distribution of the dikes depends on the strongly developed regional fractures which strike northeast (fig. 1). The dikes usually strike between 35° and 80°, but there are cases of almost meridional direction. The breccia dikes predominantly strike northwest (300° to 350°), and in some cases southwest (100° to 125°). All the breccia dikes are steep, the dip varying from 70° to 85°. In the granodiorite-porphyry massif there are a large number of fractures of similar alignment to the breccia dikes. Some of them accompany zones of mylonitization in granodiorite-porphyry.

Breccia dikes, especially those situated in the intrusives, vary in thickness in all directions. There are cases, where over a short distance, the thickness of the dike decreases from 3 m. to 1 cm. In some cases the dikes extend over 100 to 150 m. without considerable shrinking, although their thickness varies. Narrow and thick parts of the dikes are often separated by stretches of relatively constant thickness. The dikes extend over 250 to 300 m., and one may be replaced by another, without changing the general direction (fig. 1). In the direction of dip, the breccia dikes were followed for 250 m. and their termination was not observed. Breccia dikes pass from the intrusive massif to the sedimentary-tuffaceous beds without changes in their morphology of composition. Most dikes come to the surface in the recent erosional section, but "blind" dikes terminating in granodiorite-porphyry are also known.

Form and structure of breccia dikes.

Morphologic features of breccia dikes situated in granodiorite-porphyry and in argillite of the enclosing sedimentary rocks, are basically the same. They are, however, somewhat different in detail. All the dikes, without exception, situated in both intrusive rock or argillite, have characteristic straight, smooth contacts, without any traces of mechanical action. On the contact surfaces of the rock enclosing the dikes there are no scratches, cavities, or irregularities. This is very surprising in view of the softness and often even plasticity of the argillite. One gets an impression that the brecciated mass was carefully placed in the cavities cutting the argillite. We believe that such contact character is unlikely for tectonic zones in general, and for zones with considerable amplitude of displacement in particular.

As stated above, breccia dikes have uneven thickness, which varies from several meters to a few centimeters. In granodiorite-porphyry there is thickening of dikes in which breccia appears to fill the cracks between the rocks, forming irregular, nest-like deposits with angular shapes. An example of such a shape is shown in fig. 2. It represents one of the dikes discovered in the granodiorite-porphyry. Here, a large (up to 3 m.) thickening, having tongue-like protuberances of breccia into the enclosing rock, passes into a regular dike 20 to 25 m. thick, sharply limited by the tectonic dislocation.

One gets an impression, that this complex structure is due to the injection of the brecciated mass under great pressure into the system of branching tectonic fractures, limited on one side by a larger tectonic dislocation. In any case, similar brecciated formations cannot be explained by disintegration of rocks during tectonic movements,

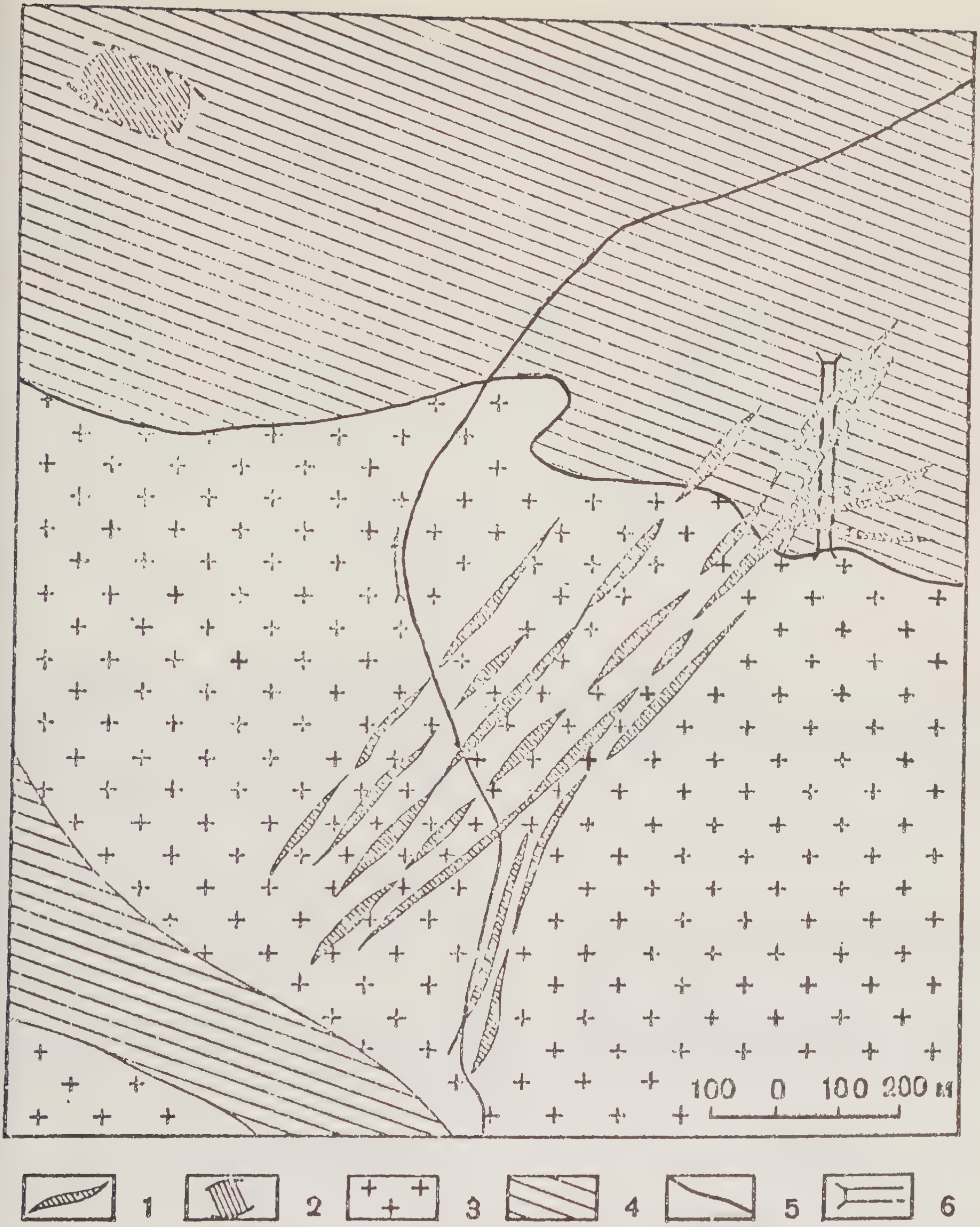

FIGURE 1. Map of the location of breccia dikes.

1 - breccia dikes; 2 - nest-like brecciated body;
3 - granodiorite-porphyry; 4 - argillite;
5 - strike of strata in argillite; 6 - gallery.

s in this case all the protuberances would e evened out, and the sharp transition from e thicker to the thinner dike would not be ossible. Breccia dikes situated in grano- orite-porphyry have characteristic step- ke contours, which we believe are caused the effect of tectonic fractures on the rmation of the dikes. This can be corroborated by a number of examples; one of them is shown in fig. 3. Here, a thick (65 cm.) breccia dike following tectonic fractures diverges into two branches. One of the branches follows the intersecting fracture and forms a sharp, almost rectangular bend, and rejoins the second branch. As a result, a complex, step-like dike is formed, enveloping

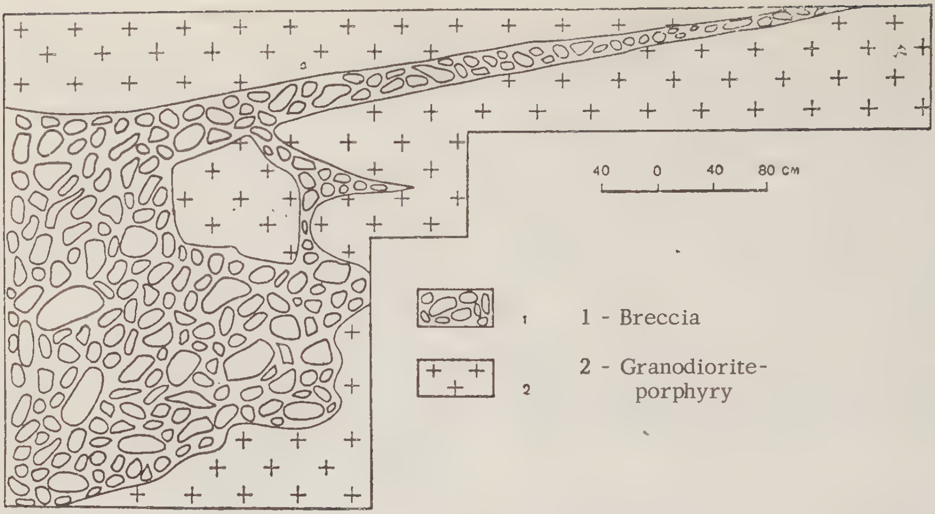

FIGURE 2. Shaft-like thickening of breccia dike.

1 - breccia; 2 - granodiorite-porphyry.

a block of granodiorite-porphyry, which itself did not suffer any displacement. This is seen from the position of the tectonic fractures intersecting the block, but not extending to the brecciated mass, which indicates that they are older than the breccia. It is characteristic that the intersecting tectonic fractures pass from one side of the breccia dike to the other without even the smallest displacement. This indicates the absence of displacement of the surrounding rocks. It is quite obvious that the step-like shape of the dike, the stability of the granodiorite-porphyry block it envelops, and the absence of displacement of the intersecting fractures are inconsistent with the theories that the breccia dike originates as the result of tectonic movements followed by the displacement of the neighboring rocks. Without postulating the displacement of the neighboring rocks it is not possible to explain the presence (in the breccia) of fragments of argillite, sandstone, tuff, etc., found in the granodiorite massif.

The nature of termination of the breccia dikes in granodiorite-porphyry deserves description. Usually, these dikes pass into a system of parallel, thin (0.5 to 3 cm.) fractures, retaining the general direction of the dike. Parts of the fractures are filled with the brecciated mass, forming thin (up to 2 cm.) breccia dikes and containing small fragments, and parts of them are filled with

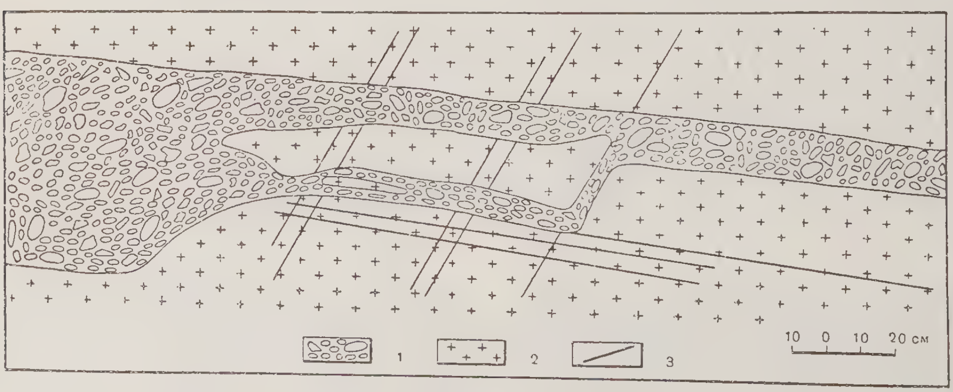

FIGURE 3. Complex breccia dike.

1 - breccia; 2 - granodiorite-porphyry;
3 - tectonic fractures.

alcite and ore mineral. These fractures eparate the granodiorite-porphyry into indi- idual blocks, in which no displacement is bserved. Also, in this case one gets an npression that the brecciated mass was ijected into the fracture system, causing no isplacement of the granodiorite-porphyry.

It is important to note the sharp difference 1 the character in which the tectonic zones nd the dikes described change when passing rom intrusive to sedimentary rocks. Numer- us observations of various intrusions in the egion indicated that tectonic zones, on pass- ig from intrusive to sedimentary strata, hange from zones of finely divided rocks and reccias to indistinct zones of folded argillite ot accompanied by breccia. At the same me the breccia dikes, on passing from itrusive to sedimentary rocks, remain ıchanged in their structure and composition. nly their thickness increases somewhat. his fact alone makes it necessary to assume critical attitude towards the theory of the ctonic nature of breccia dikes.

The following facts indicate that breccia ikes are younger than the tectonic zones hich developed in the intrusive massif, and ıat the structure of the dikes depends on ıe structure of the tectonic zones. In one f the adits (adit no. 6) the breccia dike is tuated in the granodiorite-porphyry mylonite one and at the same time the breccia is not ataclastic. The contacts between mylonite ıd the breccia dike are sharp and straight. here is no doubt that the breccia appeared fter mylonitization and that there were no ctonic movements after the formation of ıe breccia dike.

The following features, which we believe be contradictory to the theory of the tec- mic origin of the dikes, are characteristic ır the breccia dikes situated in sedimentary ocks, consisting mainly of argillite. Almost l breccia dikes cut across the stratifica- on of the sedimentary rocks (dip of dikes is)5° to 350°; dip of argillite is 10° to 30°). he altitude of the sedimentary rocks does ot change in the vicinity of the breccia kes (fig. 4). This clearly indicates the bsence of displacement during the formation f fractures.

Sometimes the breccia dikes branch almost erpendicular to the main dike; the branches e as thick as the main dike and do not tend to the other side of it (fig. 4). These anches cannot be considered as due to ore recent faults, as there are no traces tectonic movement, and there are no simi- r branches on the other side of the main ke (fig. 1). It is obvious that such structure nnot be explained by tectonic movements, ıt better by injection of a brecciated mass

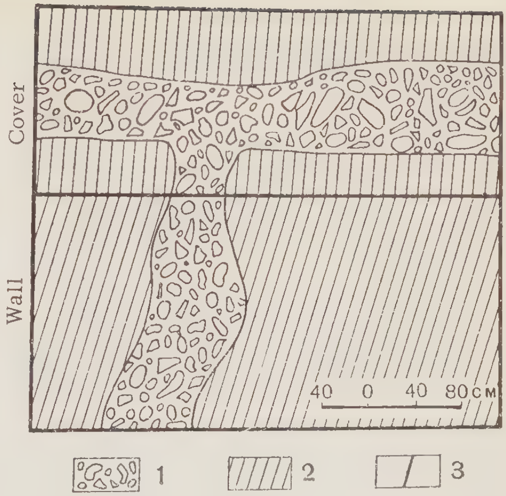

FIGURE 4. Branching of breccia dike.

1 - breccia; 2 - argillite; 3 - strike of strata in argillite.

into tectonically weakened zones. Apophyses from the breccia dikes, resembling the apo- physes of hydrothermal veins, are sometimes observed in argillite (fig. 5). The apophysis

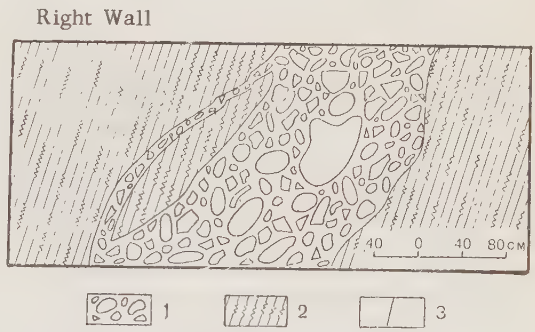

FIGURE 5. Breccia dike with an apophysis.

1 - breccia; 2 - fractured argillite; 3 - strike of strata in argillite.

shown in fig. 5 encircles a block of undis- placed argillite, as can be seen from the position of the beds. The apophyses have angular contours due, in some portions, to the filling of tectonic fractures with a brec- ciated mass, while in others, to the em- placement of the brecciated mass along the strike of the beds. It is difficult to imagine

that the formation of the apophyses, and all the structure represented in fig. 5, could be the direct consequence of tectonic movements.

A breccia dike having angular contours was encountered in the argillite (fig. 6). This

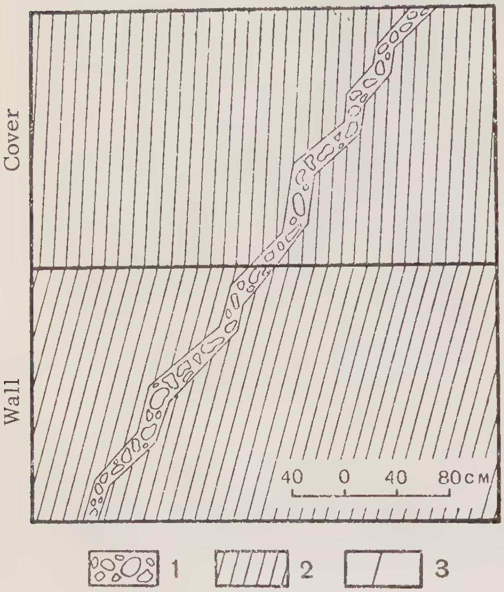

FIGURE 6. Step-like brecciated dike.

1 - breccia; 2 - argillite; 3 - strike of strata in argillite.

unusual shape could be due to the fact that in some parts the dike follows a tectonic fracture, and in other places it follows the strike of the beds. If the breccia constituting this dike was the result of disintegration and displacement of rocks during tectonic movements, there would be no such angularity.

Within the sedimentary beds, 1 km. northwest of the dikes described, a brecciated body was found having a composition analogous to that of the brecciated dikes (fig. 1). According to prospecting data, this body is a steep, isometric deposit, 40 to 45 m. wide in horizontal section; it may be a large thickening of an elongated brecciated zone.

Composition of the breccia.

The breccia, constituting the dikes described, consists of fragments of granodiorite-porphyry, diorite porphyrite, quartz gabbro-diabase, argillite, sandstone, tuff and cordierite chert, not encountered in quantity on the surface. The fragments are cemented with tuffaceous, and to a lesser degree clay-like material. A brief petrographic description of the fragments is given below.

Granodiorite-porphyry is typical for the region. Its texture is porphyritic, with a well crystallized ground mass. It contains impregnated plagioclase, usually replaced by carbonate and sericite, decomposed hornblende and quartz. Impregnations of pyrite, galena and sphalerite are also observed.

Diorite porphyrite is analogous with that widely distributed in the region. It has porphyritic texture, and ground mass is fully crystalline consisting of replaced plagioclase (predominant), potash feldspar, and quartz. The impregnations are represented by plagioclase, in most cases replaced by carbonate, sericite and kaolin, and dark minerals containing chlorite (pyroxenes). Impregnations of pyrite, galena and sphalerite are also found.

Gabbro-diabase. The texture of this rock is porphyritic. The impregnations are represented by plagioclase and monoclinic pyroxene, replaced to some extent by chlorite and carbonate. The mass is fully crystalline, has diabasic texture, and consists of carbonaceous plagioclase and monoclinic pyroxene replaced by chlorite and carbonate. Sometimes the rock contains secondary potash feldspar and quartz.

Chert consists of cordierite, plagioclase, biotite and magnetite.

Argillite is dark gray laminal rocks, usually carbonaceous, with traces of sericite and quartz.

Sandstone, quartz and quartz-muscovite are finely granular and cemented with calcareous clay.

Tuffs are of liparite type with crystallclastation. The clastic material consists of potash feldspar and quartz fragments in a felt-like cementing mass.

Fragments constitute 70 to 80 percent of the total mass of breccia, with only 20 to 30 percent of tuff-clay cement. The most commonly appearing fragments are granodiorite-porphyry, constituting 50 to 60 percent; argillite fragments make up 20 to 30 percent; fragments of other rocks are encountered relatively seldom. Among them the most common are tuff, then diorite porphyrite and gabbro diabase.

The size of the breccia fragments varies from 1 mm. to 1.5 m. The fragments can be divided into three fractions, according to

heir size: small, 1 to 10 mm., medium -- to 10 cm., and large -- 10 cm. to 1.5 m. The 1 to 10 cm. fraction is the most common. The largest fraction is represented usually by granodiorite porphyry and diorite porphyrite, although these rocks are also found in the small fraction. The rock fragments usually are rounded with angular fragments relatively seldom found. The edges are always smooth. Flattened, elongated fragments are very often found. The smoothest, round shapes include the fragments of eruptive rocks, particularly granodiorite porphyry. The argillite fragments sometimes appear to be forced or pressed into the fragments of other rocks.

There is no definite orientation of the fragments in the brecciated mass. However, in thin dikes, elongated fragments are often orientated along the contact line of the dikes. This is explained by the fact that the length of the principal axis of such fragments is greater than the thickness of the dikes, and other orientations are impossible. It should be noted that in thin (1 to 3 cm.) apophyses and in terminal parts of the dikes the brecciated material has the same composition. The only difference is in the size of the fragments, which depends on the thickness of the veinlets. The composition of the fragments is relatively constant and their distribution in the breccia dikes is relatively uniform. However, in some parts, accumulation of fragments of one rock is observed, although the distribution of such accumulations does not follow any definite rule. It is characteristic that the composition of the breccia fragments does not depend upon the composition of the enclosing rocks. Both in the granodiorite-porphyry and in argillite the composition of the fragments in the breccia is approximately the same. The cementing material consists of a finely granular mass of gray and gray-green color. Microscopic investigation revealed tuffaceous cement. It consisted of clastic material, represented by fragments of quartz and plagioclase, having sizes 0.1 to 0.05 mm. and less, and fragments of eruptive and sedimentary rocks having sizes 0.1 to 0.5 mm. The mineral and rock fragments in the cement are angular. The microscope revealed both acid and basic plagioclase, the latter not being characteristic for the eruptive rocks enclosing the diles. It should be noted that potash feldspar and quartz fragments in the cement cannot be from sedimentary formations, as they are much larger than the fragments of these minerals in argillites forming a part of the breccia.

The clastic material of the cement is contained in the felt-like binding mass, consisting of a finely divided aggregate of carbonate, chlorite, sericite and kaolin. Impregnations of pyrite, galena and sphalerite are often encountered. Sometimes, particularly in breccia dikes located in sedimentary rocks, a considerable amount of clay, consisting of finely divided argillite, is found in the cement.

Chemical analysis of the breccia cement in one of the dikes (dike no. 3), situated in granodiorite-porphyry, and free from clay-like substances, yielded results shown in table 1.

The composition of the breccia cement is similar to that of the local andesite, which suggests the possibility of genetic similarity of these formations.

The absence of granulation in the brecciated material filling the above dikes is characteristic. The most careful microscopic investigations, carried out by various petrographers at various times, failed to detect even traces of granulation in quartz, feldspar and other minerals. This fact is a serious contradiction of the dike formation theory involving tectonic tensions, leading to disintegration and displacement of rocks.

The study of the breccias indicates a constant composition of the fragmental part of the breccias of various dikes, which is independent of the composition of the enclosing rocks. This suggests a common source of the brecciated material of all the dikes. It is possible, that this source is situated at great depth.

Origin of the breccia dikes.

In view of the above discussion, it is obvious that the brecciated dikes described could not be the result of magmatic or hydrothermal activity. The formation of these dikes cannot be explained by the filling of fractures with rock fragments from above, as in the case of neptunic dikes, since "blind" brecciated dikes are encountered. Furthermore, the formation of the brecciated dikes cannot be explained by the removal of the brecciated material from lower horizons, since the sedimentary beds contain no formations involving fragments of hypabyssal rocks. Thus, of all the possible methods of formation of the breccia dikes there remain only two: tectonic and explosive. The theory of tectonic origin of breccia dikes must involve large displacement of rocks, causing the dragging of fragments of sedimentary rocks into the intrusive massif, and fragments of eruptive rocks into the sedimentary beds. The assumption of the tectonic movements of considerable amplitude is contradicted by the facts given in previous chapters. The facts are briefly stated as follows:

TABLE 1.

	I	II	III
SiO_2	59,48	57,28	59,59
Al_2O_3	14,82	11,12	17,31
Fe_2O_3	5,62	9,17	3,33
FeO	3,02	5,24	3,13
TiO_2	0,60	0,67	0,77
MnO	0,15	1,83	0,18
CaO	1,68	5,28	5,80
MgO	3,47	3,51	2,75
Na_2O	2,75	2,98	3,53
K_2O	2,16	1,68	2,04
P_2O_5	0,10	0,07	0,20
SO_3	0,20	—	—
S (sulfide)	4,50	—	—
H_2O	0,52	0,56	1,26
Losses on ignition	0,72	0,92	—
Total	99,79	100,31	

NOTE: Comma represents decimal point.

I - cement of the explosive dike no. 3 (analysis by the chemical laboratory of the L'vov expedition); II - andesite from the Banya stream region (analysis by the chemical laboratory of the mineralogy department of L'vov University); III - andesite in general (according to A.N. Zavaritskiy [2])

1. There are no traces of granulation in the brecciated material of the dikes.

2. The contact surfaces of the brecciated dikes are straight, smooth, without scratches and cavities.

3. Tectonic fractures in the granodiorite-porphyry, enclosing the brecciated dikes, pass from one side of the dikes to the other without cutting the breccias and without displacement.

4. The strata of the sedimentary rocks approach the brecciated dikes without flexures or folds in the zone of contact with them.

5. The contours of the brecciated dikes are step-like and angular; the transition from widening to constriction is sharp and angular.

6. Branching and apophyses from the brecciated dikes are observed.

The splitting of the breccia dikes into thin brecciated veinlets, which does not involve the displacement of the enclosing rocks divided by them, and also the uniform composition of the fragments in the breccia, and its independence of the composition of the enclosing rocks, cannot be explained from the point of view of the tectonic origin. In addition, the tectonic zones of the region differ sharply in their morphology, structure and composition from the breccia dikes. This is particularly noticeable on passing from eruptive rocks into sedimentary rocks.

All the above facts exclude the possibility of correlating the breccia dikes with formations originating from tectonic movements, which cause disintegration and displacement of rocks in the fault zone. It can only be stated, that the tectonic dislocations already formed determined the localization of the breccia dikes. Consequently, the last of all the possible theories -- the explosive origin of the breccia dikes -- remains to be considered. We shall begin the discussion of the explosive mechanism of breccia dike formation by reviewing some of the features of

olcanic explosions in general.

It is known that the explosions are due to he rising column of magma, in the upper arts of which large quantities of volcanic ases accumulate due to crystallization, ecreased pressure and absorption of water. udden decrease of the external pressure, aused by the piercing of the upper strata of ocks by the compressed gases, or by tec-onic forces, is accompanied by the evolution f large quantities of gases with so great a orce and rate that an explosion takes place.)uring the explosion the magma boils and isintegrates, forming small particles, which re ejected as a stream of quickly setting ava, together with fragments of minerals vhich separated earlier. As a result of the xplosion cylindrical channels are formed -- 1 the strata of rocks -- the craters of erup-ion. Through these channels passes only yro-clastic material together with the gases, ut not lava (Katmayskiy type of eruption).)uring the explosion, the gases under great ressure penetrate into the walls of the rater and into the fissures connected with 1em. After the explosion, when the pressure ecreases, the gases quickly escape from the all rock. This is accompanied by the detach-1ent of rock fragments which are included in 1e total stream of the explosive process, nd which fill, together with the volcanic 1aterial, the crater formed by the eruption. his is in effect the secondary explosion of 1e walls of the crater. Such case of "autho-enic explosive breccia" was described by ust [9] for craters in Missouri.

S.V. Obruchev [4], on the basis of data egarding craters of South Africa, Swabia 1d Arizona, proposed a theory that the xplosions of magma, accompanied by the volution of gases and the formation of raters, takes place at the depth of 1,200 to 300 m. Cases are known when the rock agments created by the volcanic explosions ll not only the channels opened by the gases, it also other cavities and weak zones of the arth's crust. This leads to non-vertical xplosive deposit formations which often do ot reach the surface. For example, the bular Stantrg deposit in Yugoslavia, con-sting of volcanic breccia, was found near e contact zone between shale and crystalline mestone where an anticlinal flexure had used intraformational openings. These open-gs were used for the injection of breccia iring the explosion. As a result, the brec-ated body is not vertical, which is usual r the crater formations, but at an angle of $)^{o}$ [7]. In Leninogorsk, Altai, there are 1own intersecting and conformable brec-ated deposits accompanying fractures and ructures situated between the strata. These eposits are of extremely irregular shaft-ce, and mushroom-like shapes, and are usually non-vertical. As a rule the brecciated deposits do not come to the surface, terminating in aleuropelites. M.V. Tashchinina [6] believes that these brecciated deposits are volcanic, eruptive formations. In Trans-Carpathia, in the Olenev region, there is a steep (75^{o} to 80^{o}), lenticular deposit of volcanic breccia, accompanying a tectonic dislocation. In some places this deposit terminates in enclosing rocks and does not come to the surface.

We believe that the mechanism of brecciated dike formation in Trans-Carpathia is the same as that of the brecciated deposits in Stantrg and in Leninogorsk. The basis of our belief is as follows.

Explosions of volcanic gases in a mass of rising magma of basic composition took place at a considerable depth (more than 500 m.) in the development area of the breccia dikes. During the explosions, the volcanic gases (including superheated steam) penetrated into the walls of open channels under great pressure, and perhaps also into closed chambers. The openings were formed as the result of the explosions, and as parts of tectonic fractures, which appeared in this region on the surface. After the explosion, with decreasing pressure, due possibly to the sudden opening of fractures, the gases rapidly escaped from the walls of the volcanic chambers and fractures, thus causing the second explosion accompanied by the splitting of large quantities of enclosing rock fragments. These fragments together with pulverized particles of magma, were driven by the gas pressure and became embedded in the upper parts of the fractures. In some cases they remained under the surface and in other cases reached it. Since this was accompanied by cooling, the fragments were carried along the fractures by water from condensed steam forming a mobile mixture with considerable internal gas pressure.

This was the process which resulted in the formation of the breccia dike, the fragmental part of which consists of rocks from a considerable depth, and the cement of finely divided materials of volcanic origin and, possibly, from pulverized lava. To a lesser degree the cement also contains pulverized particles of the enclosing rocks.

The breccia dikes of Trans-Carpathia both in morphologic characteristics and in composition and the character of the breccias resemble the dikes described by lowering [3], who believes that they are of explosive origin. The hypothesis of the explosive origin of the breccia dikes is in agreement with the geologic history of the Vyshkov region, and explains all the properties of these dikes, which cannot be accounted for by other

genetic theories.

It was shown in the first section that the volcanic activity in the region began after the appearance and stabilization of hypabyssal intrusions, in which the breccia dikes are situated. This activity was the origin of both effusive formations and explosive necks, the composition of the latter being similar to the composition of the described dikes. Thus the formation of the explosive breccia dikes can be correlated in time and space with the phase of volcanic activity. Convincing evidence of the volcanic origin of the breccia is provided by the tuffaceous character of the cement. Its composition corresponds to andesite, which is found in the region and is related to the same phase of volcanic activity as the breccias.

The smoothness of contact of the enclosing rocks with the dikes indicates that the brecciated material was brought from lower strata. The uniform composition of breccias from various dikes and its independence of the composition of the enclosing rocks suggests the same source of the brecciated material for all the dikes. Such characteristic features of the breccia dikes as the absence of granulation, scratches on the contact areas of the enclosing rocks, displacement of the neighboring rocks, as well as the angular contours of the dikes and characteristic thickening and branching of the dikes, can readily be explained by the explosive nature of the breccias. This is especially true when it is remembered that the brecciated mass was injected into the fractures, under pressure of gases, in the form of a mobile mixture with water.

In conclusion, it should be noted, that the understanding of the breccia dike origin in the Vyshkov region will enable the geologists to separate brecciated zones into tectonic and volcanic formations. This is necessary for estimating the practical value of these zones. It should be assumed that by careful investigation many brecciated zones, now considered as tectonic, will be included in the group of explosive formations.

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Iv. Franko State University of L'vov

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TECTONIC MAP OF THE TURKMEN-KHORASSAN MOUNTAINS

by

I. A. Rezanov

ABSTRACT

This paper describes the tectonic map of the Turkmen-Khorassan mountain. The map has ›een constructed by the separation of structural units which differ from each other in the time ›f formation of flexures and the time of upheavals which altered these flexures. The non-ıniform character of folding movements is shown by the age of folding and morphology of the olded structures.

* * * * *

INTRODUCTION

The Turkmen-Khorassan mountains are ituated between the Kara-kum deserts in the orth and Dest-i-Kevir in the south. Only he northern fringe of this folded system is ituated in the Soviet Union, and the greater art of it is south of the border of the State.)bviously it is impossible correctly to under-tand the tectonic structure of the Soviet :opet-Dag and its situation in the whole ystem of the alpine geosynclinal region vithout at least a brief review of the tectonic tructure of the whole system of the Turk-ıeno-Khorassan mountains.

This paper describes the tectonic map of ıe Turkmen-Khorassan folded system and ome of the structural units belonging to it: ıe Cis-Kopet-Dag front flexure, the Trans-:aspian fault, and Bol'shebalkhano-Kubadag nticline. The better known Soviet part of ıe territory can be treated in more detail ıan the territory beyond the border. How-ver, the author was trying not to overload ıis part of the map by the separation of maller structures or tectonic zones, as his urpose was to depict the tectonics of the 'hole Turkmen-Khorassan folded region.

The construction of the tectonic map is ased on the principle, formulated by '.V. Belousov, of dividing regions on the asis of the types of tectonic development nd morphological properties [2]. My studies f the folding movements [29, 30] make it ossible to separate tectonic zones in the 'urkmen-Khorassan mountains which differ from each other in the time of formation of large flexures and the time when movement altered these flexures.

The differences in the history of the vertical movements in this territory were shown in the different ages of formation of folds in these zones. Tectonic zones having a similar history of folding are usually characterized by the simultaneous formation of folds. In such zones the same type of fold is also frequently observed. Thus the differences in the character and time of the folding lead to the differentiation in the age of fold formation and morphology of folding. Similar zones usually contain similar formations. While considering the differences in the folding as the basis of the classification of tectonic structures, we take into account all, or almost all the complex of other factors characterizing the tectonics of the zones, namely the age of the fold formation, morphology of the folded structure, and the distribution of the geological formations.

Previous workers carried out the separation into tectonic regions only in the Soviet part of the territory [6, 11, 23], where the uniformity of the tectonic structure of Kopet-Dag was observed, extending over more than 500 km. Along all the northern fringe of Kopet-Dag there was drawn the anticlinal zone of the front ridge, south and parallel to which are situated a number of folds. The complex tectonics of the Archman-Nukhur "knot" [10, 17], involving northeast trends,

was explained by the pressure from the south, at the top of the arc, on the solid platform north of Kopet-Dag [11].

The first paper, in which data were given [18] on the eastern part of Kopet-Dag, situated abroad, proved the complex zonal structure of this part of the Turkmen-Khorassan mountains. The construction of the western part of the tectonic map was carried out by B.A. Petrushevskiy, I.A. Rezanov, V.A. Rastvorova and N.N. Leonova, utilizing the available foreign data [26]. This work put the tectonic structure of this territory in a different light. Many theories proposed in the above work are developed in the present paper in the light of the more recent data and with more detailed consideration of the material. The new data include the separation of the large Kopet-Dag anticlinorium, which has a different history of development, from the more recent West Kopet-Dag, which has a mosaic structure. From the latter were separated the structurally complex tectonic zones of Ezzet-Karagez and Aladag-Kulmach, which were formed by post-Akchagylian folding. The above paper showed the basic differences between the frontal anticlines of West Kopet-Dag, terminating in Bakharden, and the structures of Central Kopet-Dag. However, in the case of some hyoptheses, for example, the tectonic nature of the Transcaspian fault and of the Bolshoy Balkhan, the author has changed his previous views. Recently P.I. Kalugin [8, 9], giving the data on the foreign part of the territory, separated within the Turkmen-Khorassan mountains the Dzhagatay. Aladag and Kopet-Dag zones, but described only the last one. He continued to accept the theory of the single front anticline stretching along all Kopet-Dag, but he separated the western Kopet-Dag (except the frontal ridge), as an independent zone. The history of theories about the tectonics of Kopet-Dag is found in a number of papers [9, 12, 26]. In the Turkmen-Khorassan mountains and in the folded fringe encircling them, the following tectonic zones can be separated. Each zone is characterized by a different history of development and different morphology of folded structures.

Strongly Elevated Zone of Large Flexures in the Beginning of the Alpine Cycle, Starting with the Cretaceous (Axial Parts of El'burs and Aladag-Binalud Mega-anticlinoria).

One of the largest tectonic zones is the system of the axial parts of El'burs and Aladag-Binalud mega-anticlinoria. In both zones large flexures appeared in the Jurassic period. At the beginning of Lower Cretaceous times upheavals and folding began in this zone. These movements formed the main features of the present-day structure of the zone. The folds of the El'burs mega-anticlinorium form a gigantic arch, convex toward the south [33]. Its central part, between Teheran and the 54th meridian has the most complex structure. Here, both in the meridional direction and in the direction of the ridge, a number of tectonic zones are observed. The zones have different structures and histories of development. The central, axial part of the El'burs mega-anticlinorium consists of the anticlinoria of north El'burs and Demavend. The former, in the western part, consists of Paleozoic rocks, which are replaced by Jurassic. On the meridian of the river Kheras there are again Paleozoic rocks. Toward the south is the Lar synclinorium, which is filled by a 3 kilometer complex of predominantly tuffaceous deposits of Eocene age [39]. In the south it is surrounded by the Demavend anticlinorium, consisting of a number of wing-like anticlinal folds, which are composed of Jurassic rocks, but often containing Paleozoic rocks. In the center of this zone rises the cone of the Demavend volcano, consisting of anderites. On the north flank of the El'burs mega-anticlinorium there is a tectonic zone of sediments of Upper Cretaceous and Neocene age, bounded in the south and east by Jurassic and older rocks. This part of north El'burs, unlike its central parts, was strongly folded in the Upper Cretaceous, and then after relative elevations of the earth's crust in the Paleocene, was depressed again in the Miocene and Pliocene. There is developed here a system of fairly simply constructed folds, which dip to the east and northeast under the Quaternary deposits. The folds formed mainly during the pre-Dakchagylian phase of folding, although the folded structures certainly underwent considerable change during the post-Akchagyl time. The Anti-El'burs anticlinorium extends south of the El'burs ridge [40]. It is separated from this ridge by a valley filled with Quaternary deposits. Teheran is in the west part of the valley. The Anti-El'burs anticlinorium is made up of Tertiary, Cretaceous and Jurassic rocks. This anticlinorium appeared where there are large Eocene and Miocene folds.

While discussing this part of the mega-anticlinorium, it should be noted that here there is no single large anticlinal formation of the High Caucasus type. The Central El'burs has a mosaic structure and consists of a system of individual anticlinal and synclinal zones. Each zone is characterized by its own properties: the type of folding in Cretaceous, Paleocene, and Neocene periods, and the different morphology of the structures. In this respect the Central El'burs resembles the Small Caucasus.

East El'burs has a simpler structure. Here, according to incomplete data [3], there is only one large anticlinorium. It is made up of Jurassic rocks, among which are found Paleozoic rocks in individual massifs. These are strongly developed on its northwest flank, where Carboniferous limestone is in contact with Quaternary deposits of the Trans-Caspian fault zone (possibly along a fault line). The Aladag-Binalud mega-anticlinorium, situated in the east, is as large as the El'burs mega-anticlinorium. In the west it consists of a number of ridges, the largest of which is Ala-Dag. The eastern part of the mega-anticlinorium is within the limits of the Binalud ridge (Kukh-i-Mirab) and is separated from the Ala-Dag by the transverse depression in the meridian of Novyy Kuchan.

The Ala-Dag part of the formation is still very little known. However, three large anticlinoria can be separated:

1) Northern-Mulgazar -- extending latitudinally from the peaks of Gorgan to Budzhnurd, consists of a number of large anticlines, briefly described by L.S. Librovich [13]. The nuclei of these anticlines are Paleozoic rocks, and the flanks are Upper Jurassic, Cretaceous and Eocene rocks. Here there are strongly developed fan-shaped and recumbent folds, which are complicated by faults. The eastern part of the anticlinorium has a simpler structure.

2) Ala-Dag anticlinorium proper, situated farther south, is in the center of the western part of Ala-Dag Binalud mega-anticlinorium. Its strike changes from southwest in the west to southeast in the east. The structure of this anticlinorium is not less complex than that of the Mulgazar anticlinorium, which can be inferred from the brief descriptions of P.I. Kalugin. In its northern fold, consisting of limestones of Middle and Upper Jurassic periods, the strata are vertical and in places are overturned. The structure here is complicated by intense secondary folding, and it is possible that the entire flank is displaced toward the north.

3) The anticlinorium of the Gazan and Salyuk ridges is more to the south. The map by Clapp [38] shows Paleozoic rocks strongly developed here.

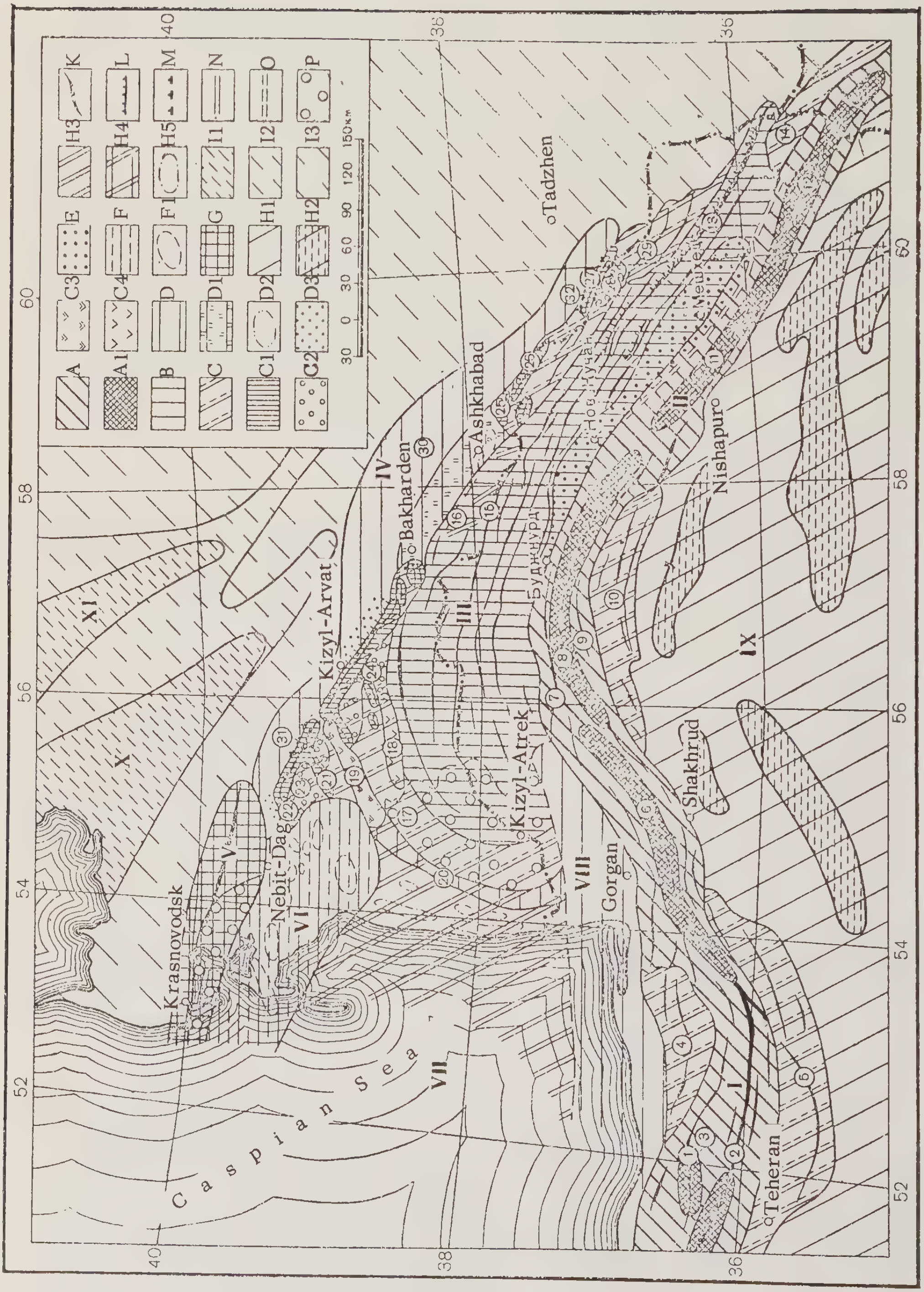
South of Ala-Dag is the region of development of Upper Cretaceous and Eocene rocks [41]. It is possible that we are dealing here with the zone of large Upper Cretaceous and Paleocene folds extending on the south flank of the Ala-Dag-Binalud mega-anticlinorium.

The western part of the Ala-Dag-Binalud mega-anticlinorium is represented by the large Binalud anticlinorium, which is better known than the Ala-Dag anticlinorium. This has been studied by: A.F. Sosedko [32], F. Clapp [38], E. Bonnard [37] and V.P. Miroshnichenko [18]. However, the complex structure of this formation is still not completely known. The axial part of the Binalud anticlinorium consists of metamorphosed rocks of Lower Paleozoic age (possibly also Pre-precambrian) and eruptive rocks, among which granites are very prominent. Lower Jurassic shales are also strongly developed. In the northern flank are found Middle and Upper Jurassic and Lower Cretaceous rocks. In the southern flank Eocene and Miocene deposits are encountered in some places. E. Bonnard separates here the folded structures of various ages. He subdivided the metamorphosed shales into three series, according to the degree of metamorphism. They have northeast direction, are intensely dislocated, and represent a sharp contrast to the Liassic beds, which are folded into much straighter and wider folds of northwest axes, corresponding to the direction of the Binalud anticlinorium.

When discussing the whole El'burs-Aladag system it should be noted that, according to the available, incomplete data, its geological structure is much more complex than the structure of the Kopet-Dag anticlinorium, which is more to the north.

The pronounced dislocation of the Lower Paleozoic rocks indicates that Caledonian folding was here very intense and, conversely, Hercynian movements were weak. Pre-Jurassic folding was much stronger; the Jurassic formations here rest unconformably on the underlying strata.

The formation of the main features of the present day folded structure of the El'burs and Aladag-Binalud mega-anticlinoria was taking place in the beginning of the Lower Cretaceous epoch after the change of geotectonic conditions. In the Binalud ridge the Aptian and Albian strata form very broad folds and occur transgressively with respect to the basal conglomerate, mainly on strongly dislocated Jurassic and older rocks. At the end of the Jurassic period there appeared the granitic intrusions of the Binalud ridge [37]. In central El'burs, as apparently also in other parts of this zone, pre-Eocene folding was of considerable importance, during which the formation of the axial parts of the mega-anticlinoria was basically terminated. The flanks of the mega-anticlinoria were folded much later, in the Upper Miocene and in the Pliocene.


Krasnovodsk
Nebit-Dag
Kizyl-Arvat
Bakharden
Ashkhabad
Tadzhen
Kizyl-Atrek
Gorgan
Shakhrud
Nishapur
Teheran
Caspian Sea
150 км

Tectonic Map

Constructed by I. A. Rezanov, according to the data of Yu. N. Godin, P. I. Kalugin, G. A. Kalyaev, N. P. Lippov, V. P. Miroshnichenko, V. N. Ognev, B. A. Petrushevskii, M. P. Sukacheva and others, with author's observations.

A -- Zone of large folding in the beginning of the Alpine cycle, constantly uplifted since the Cretaceous period (central parts of El'burs and Aladag-Binalud mega-anticlinoria); A_1 -- Axial parts of mega-anticlinoria in which Paleozoic nuclei are exposed. B -- Zone of large folding in the Lower Cretaceous period, uplifted since the Upper Cretaceous period (South Kopet-Dag anticlinorium). C -- Zones of large folding in the Upper Cretaceous period and in the Paleocene (folded flanks of the mega-anticlinoria); C_1 -- Large asymmetrical anticlines; C_2 -- Flat cavities filled with weakly dislocated Neocene rocks; C_3 -- Ezzet-Karagez zone; the region of large Neocene folding, intensely folded at the end of Pliocene; C_4 -- Aladag-Kulmach zone, of less intense post-Akchagylian folding; D -- Frontal folds; the region of important Neocene and Quaternary subsidence; D_1 -- Ashkhabad part of the fold; D_2 -- Quaternary brachy-anticlines; D_3 -- Zone of the development of Pliocene-Quaternary folding in the frontal fold; E -- Pliocene-Quaternary fold; F -- Zone of large folding during the entire Mesozoic and Cenozoic eras; F_1 -- Dome-like folds from Pliocene and Quaternary periods; G -- Parageosynclinally developed zone; the region of large Jurassic and smaller Cretaceous folding; H -- Central massifs; H_1 -- Central Iranian massif; H_2 -- Anticlinal structures within the central Iranian massif; H_3 -- Central South Caspian massif; H_4 -- Shakhman fold; H_5 -- Large, sloping brachy-folds in Pliocene rocks.

I -- Epi-Paleozoic platform; I_1 -- Mega-anticlines of the platform; I_2 -- Underground slopes of the mega-anticlines; I_3 -- Valleys of the platform; K -- Axes of the anticlinal folds; L -- Overthrust faults; M -- Probable overthrust faults; N 00 Faults; O -- Probable faults; P -- Parts of folded structures submerged under Pliocene and Quaternary formations.

I - El'burs mega-anticlinorium: 1- North-El'burs anticlinorium, 2- Demavend anticlinorium, 3- Larsk syncline, 4- folded zone of the northern flank of El'burs mega-anticlinorium, 5- Anti-El'burs anticlinorium, 6- East El'burs anticlinorium.

II -- Anadag-Binalud mega-anticlinorium: 7- Mulgazar anticlinorium, 8- Ala-Dag anticlinorium, 9- South Ala-Dag anticlinorium, 10- folded zone of the southern flank of Aladag-Binalud mega-anticlinorium, 11- West Binalud anticlinorium, 12- East Binalud anticlinorium.

III -- Kopet-Dag mega-anticlinorium: 13-Muzderan anticlinorium, 14- Salekhabad synclinorium, 15- Kheirabad-Gaudan anticline, 16- Uli-Top anticline, 17- Messerian- Khodzhakala zone, 18- Aladag-Kulmach zone, 19- Ezzet-Karagez zone, 20- Shakhman fold, 21- Danatin anticline, 22- Malyy Balkhan anticline, 23- Danatin syncline, 24- Khodzha-Kala syncline, 25- Gyaur anticline, 26- Zirakev anticline, 27- East Kopet-Dag anticline, 28- Kelyatin syncline, 29- Sulakh anticline.

IV -- Cis-Kopet-Dag fold: 30- Ashkhabad valley, 31- Kazandzhik valley, 32- Kaakhkin valley, V- Bol'shebalkhan-Kubadag anticlinorium, VI- Pribalkhan valley, VII- Keymir-Chikishlyar sunken central massif, VIII- North El'burs frontal fold, IX- Central Iranian massif, X- Tuar-Kyr mega-anticline, XI- Goklenkuyusin mega-anticline.

Zone of Large Folds of Lower Cretaceous Age, Steadily Elevated Since the Upper Cretaceous (South Kopet-Dag Anticlinorium)

The large Kopet-Dag mega-anticlinorium is situated north of the El'burs-Aladag-Binalud arch. The principal difference between it and the above folded formations is that in the Lower Cretaceous epoch, when folding ceased in the Aladag-Binalud zone, it formed the largest flexures, exceeding in its central part 3, 500 m. In the Upper Cretaceous, this single large Lower Cretaceous fold underwent sharp changes; the regions which underwent the strongest folding in the Lower Cretaceous became relatively elevated in Upper Cretaceous times and only during the time of great transgressions were covered by the sea. The zones of large Upper Cretaceous folds were displaced northward into the outer regions of the Lower Cretaceous fold. The same distribution of folds and uplift persisted during the Lower Tertiary [29]. The real difference in the character of folds in the southern regions of the Kopet-Dag mega-anticlinorium and in its northern fringe were later reflected by the different ages of folding and by the different morphology of the folded structures. All this makes it possible to divide the Kopet-Dag mega-anticlinorium into two tectonic zones: the South Kopet-Dag anticlinorium, which we are about to describe, and the folded zones of the northwestern and northeastern blanks of the mega-anticlinorium.

In the greater part of the area of the South Kopet-Dag anticlinorium, which P.I. Kalugin named the "Principal" anticlinorium [9], from three to six parallel anticlinal chains are observed, which change direction from northwest in the east to northeast in the disappearance of the anticlinorium in the west. In general it is parallel to the direction of the Aladag-Binalud mega-anticlinorium. Each chain consists of a number of large anticlinal folds, usually terminating periclinally and consisting of Neocomian limestone and in places Upper Jurassic limestone. Aptian, Albian and more rarely, Upper Cretaceous rocks are found in the synclines. According to P.I. Kalugin, the majority of folds have fan-like, twisted, and box-like shapes. In the northern ridges they extend to the north of the central anticline, and in the southern ridges, to the south. However, neither the protrusions nor the displacements are very pronounced and only slightly complicate the box-like structure of the folds.

In the western end of the anticlinorium west of the 57th meridian, the character of the folding changes radically. The box-like folds gradually pass into straight, flat folds having dips of 10 to 20^{o}, in a few places increasing to 30 to 40^{o}. This takes place on the background of a general sinking of the South Kopet-Dag anticlinorium. Neocomian limestones are here replaced by Aptian and Albian sandstones. The general northwestern directions change into latitudinal and then southwestern trends. The distances between the anticlines increase and in consequence the width of the anticlinorium increases from one and one-half to twofold. Geophysical data indicate that the South-Kopet-Dag anticlinorium does not terminate on approaching the plains of the Transcaspian lowlands but continues within its limits covered by Pliocene and Quaternary rocks. It gradually changes its direction toward the southwest to a meridonal trend.

Situated within the U.S.S.R. is only the Kheyrabad-Gaudan asymmetric anticline which extends along the border of the state for over 150 km. Its northern flank is flat (dip, 10 to 20) but is complicated by a system of faults and by longitudinal and transverse bends. An example is the "half-fold" of the Dushak mountain. The faults, which are sometimes situated diagonally to its strike, are described in detail by P.I. Kalugin [7]. Both the author and L.N. Leontev [12] were unable to observe in them large horizontal displacements. The southern flank of the anticline is steep; in some cases the layers are vertical or are even overturned. More to the north, between the Kheyrabad-Gaudan anticlinal uplift and the foot plain before the mountains, is a group of brachi-anticlinal folds of Neocomian origin. They are separated from the Kheyrabad-Gaudan anticline by several flat synclines filled with Lower Cretaceous and partly with Upper Cretaceous rocks. These brachi-anticlines form the Murab-Kerik, Uli-Top and Markou ridges. The brachi-anticline of Uli-Top is the largest, being more than 25 km. long. As in the case of other anticlinal structures of this zone, the southern wing of Uli-Top is steeper (dips 20 to 60^{o} and more), and in the western part it is complicated by a fault. The northern flank is very flat; the slopes here do not exceed 10^{o}. The width of this flank is not everywhere uniform; in the central part, the folds extending over 2 to 4 km. increase toward the northwest up to 10 km. Here, the flank is complicated by a small syncline, the northern, steep, flank of which is displaced by a fault. Neocomian limestones here are in contact with Tertiary formations. Along the northern limit of this anticline P.I. Kalugin [6] and others draw a single zone of large faults, although in many cases there are no reliable data. According to our observations, the line of faults can be observed only in some brachi-anticlines, without joining them up in one single zone. This was already stated by L.N. Leontev

[12]. Toward the southeast the frontal anticlines are absent, and the Kheyrabad-Gaudan anticline is in direct contact with the premountain flexure.

The fore-folds of the central part of Soviet Kopet-Dag, studied by P.I. Kalugin and others, form one system of frontal anticlines, together with the frontal ridge of western and eastern Kopet-Dag. We believe that it is impossible to separate such a single anticlinal zone extending over all Kopet-Dag. This is contradicted by both the conclusions from the history of geotectonic development, indicating the differences in the formation of structures of western Kopet-Dag and the northern flank of the eastern Kopet-Dag on the one hand, and folds in the northern limit of central Kopet-Dag on the other, and by differences in the structure of these zones.

Fore-front anticlines of the central Kopet-Dag have a number of different properties in spite of their apparent structural similarity to the frontal ridge of the western Kopet-Dag. In contrast to the frontal anticlines of the western and eastern Kopet-Dag, the folds of Uli-Top and Markou have steep southern, but not northern flanks. The property, exhibited only by these anticlines, is the presence of small synclinal folds complicating their flat northern flanks. This constitutes the real difference between the anticlines of Uli-Top and Markou and the frontal anticlines of the western and eastern Kopet-Dag. This is not the only difference between the structures of the fore-front anticlines of the central Kopet-Dag and the western and eastern Kopet-Dag. As we shall see below, in western and eastern Kopet-Dag, north of south Kopet-Dag anticlinorium, there is a zone of folds 20 to 30 km. wide, and in western Kopet-Dag up to 60 km. wide, instead of individual anticlinal folds, as in central Kopet-Dag. The anticlines of the so-called frontal ridge of western and eastern Kopet-Dag form a part of this zone. Obviously, the individual folds, developed in the northern limit of the anticlinorium in central Kopet-Dag (but only in a part of it), cannot correspond to these large tectonic zones. These folds should be considered as a complication appearing in the northern anticlinal chain of the south Kopet-Dag anticlinorium and should be included in the composition of the latter.

While concluding the description of the tectonics of the south Kopet-Dag anticlinorium it should be emphasized that its structures are of much more recent origin than those of the El'burs and Aladag-Binalud mega-anticlinoria. Pre-Cretaceous folding, strongly developed there, is almost absent in south Kopet-Dag anticlinorium. Insignificant movements were taking place in the central and southeastern regions of the anticlinorium up to recent times. Folding and elevation of the south Kopet-Dag anticlinorium began at the end of the Paleocene. These facts are proved by the clays, sands, and conglomerates of Karagaudanian type belonging to the end of the Oligocene and the Lower Miocene. The presence of Neocomian limestones in the upper horizons indicates that at that time the axial part of the anticlinorium was already eroded to Neocomian rocks. The final formation of folds of south Kopet-Dag anticlinorium was terminated in Akchagyl time [30].

Zones of Large Folds of Cretaceous and Paleocene Age, Folded in the Pliocene Period

Zones, characterized by large folds of Upper Cretaceous, Paleocene and sometimes largely of Neocene age, are further separated in the tectonic map. Resting on the flanks of mega-anticlinoria in various regions of the territory considered, these tectonic zones have a number of common features. In addition to the same type of folding, they are characterized by a pre-Akchagyl type of folding and the development of folds having predominantly comb-like shapes. Such zones comprise: northwest and northeast flanks of Kopet-Dag mega-anticlinorium, part of the northern flank of El'burs mega-anticlinorium, large anti-El'burs anticlinorium and part of the southern wing of Aladag-Binalud mega-anticlinorium.

Below, continuing the description of the Kopet-Dag mega-anticlinorium, we consider its flanks. The few available data on the structure of the other zones, situated on the flanks of El'burs and Aladag-Binalud mega-anticlinoria were given above.

Northwest Flank (West Kopet-Dag)

Northwest of South Kopet-Dag anticlinorium is situated a complex folded zone of the relatively low northwestern flank of Kopet-Dag mega-anticlinorium (West Kopet-Dag), which was first isolated as an independent structure by B.A. Petrushevskiy [26]. It differs from the South Kopet-Dag anticlinorium both in its history of development and in its structure. A number of tectonic units were isolated here.

Along the northern limit of Kopet-Dag there extends in a northwestern direction the asymmetric anticline of the frontal ridge. It consists of two large folds, separated by a

sharp incline in the region of Iskander. Along its northern flank V.N. Ognev [24], P.I. Kalugin [6, 9], G.I. Kalyayev [11], and others, observed a zone of large displacements and believe that it is of considerable local importance. Old, pre-Akchagylian faults, appearing in the upturned northern flank, can be observed in several places; their amplitude should be estimated as 2 to 3 km. However, they often disappear and cannot be traced for several kilometers. Post-Akchagylian displacements were insignificant (up to 200 to 300 m.) and can be observed only at isolated points. The above facts indicate that this zone of faults cannot be considered as a single structurally independent one. It represents only the complication of some parts of the anticlines of the frontal ridge [27].

The so-called Archman-Nukhur "tectonic knot" [10, 17] is situated in the southeastern extension of the frontal anticline. In this region of the frontal anticline, its trend, which was northwest from Iskander to Bama (about 170 km.), sharply changes to northeast. The anticline abruptly terminates after the change of direction. It is linked to several other brachyanticlines which have also northeast strike. The Archman-Nakhur "knot" should be considered as the eastern end of all the tectonic zones of the western Kopet-Dag. Several scalloped folds with a southwest strike separate from the anticline of the front ridge. These folds are the Eyshem and Oboy anticlines and further southwest the Danatin anticline. The extreme western structure of these scalloped folds is Malyy Balkhan, a large asymmetrical brachyanticline with a steep northwest flank. In the northeast end of the Malyy Balkhan there is observed a smooth bend having a direction from southwest (characteristic for the scalloped anticlines) to southeast [28]. More to the east the underlying rocks are covered by Quaternary formations.

Geophysical work interpreted by Yu. N. Godin between Malyy Balkhan and Kopet-Dag indicates a distinct subterranean link, in which Mesozoic rocks are found not far from the surface. This indicates that Malyy Balkhan belongs not only to the Kopet-Dag system, long ago assumed by P.I. Kalugin, but also to the structural zones corresponding to the frontal anticline of the western Kopet-Dag and branching from it as scalloped folds.

Between the scalloped folds branching from the frontal anticline are situated the large, flat, Danatin, Uzek-Dag and Khodzha-Kala synclines filled with Neocene rocks. More to the south in Paleocene formations are observed relatively simple folds of latitudinal and southwest direction, which are characterized by frequent elevation and depression along their hinges.

Along the northwestern limit of South Kopet-Dag anticlinorium, in the direction southwest of Khodzha-Kala region, extends a tectonic zone, the greater part of which is found covered by Pliocene and Quaternary formations. In the Messerian region the zone assumes gradually a meridional direction. Yu. N. Godin and the author called it the Messerian-Khodzha-Kala zone. In contrast to the large and sloping submerged folds of the South Kopet-Dag anticlinorium, the submerged folds of the Messerian-Khodzha-Kala zone are smaller and have a more complex structure. According to seismographic data, along the northwestern limit of this zone extends a submerged system of anticlinal folds, possibly broken by a fault as it is in the case of the frontal ridge of the West Kopet-Dag; west of it is the Shakhman Neocene flexure.

Within the limits of the Messerian-Khodzha-Kala tectonic zone is the so-called Aladag-Kulmach zone of synclinal ridges of Neocene rocks. Here, long linear folds are seldom encountered and brachyanticlinal structures are more developed, sometimes with wide flattened synclines.

The above structures of West Kopet-Dag were formed in pre-Akchagylian time. Later there took place only a general elevation of the frontal zone, some other anticlines, and faulting. The post-Akchagylian folding was more intense in the Aladag-Kulmach zone. However, within the limits of West Kopet-Dag is situated the Ezzet-Karagez tectonic zone, where post-Akchagylian folding completely altered older structures. The zone extends in the southwest direction of the Iskander region to the western end of Kopet-Dag. Here are narrow (2 to 3 km. wide) anticlines and synclines. These are made of Neocene and Paleocene rocks and extend sometimes over 30 to 50 km. The flanks of many of them dip 60 to 80°; some of the flanks are overturned. Probably a considerable number of faults are present here, and we were able to observe some of them. At the northeastern end of the Ezzet-Karagez zone, periclinal closing of its structures is observed. This region is connected with the deep sinking of the hinge of the anticline of the frontal ridge in the Iskander-Uzun-Su sector. According to seismographic data [4] in this locality the sinking of the roof of the Paleozoic basement also is indicated.

The Shakhman flexure is the direct continuation of the Ezzet-Karagez zone in the southwest direction. In the Neocene both structures represented one belt of large folds extending northwest of the Messerian-Khodzha-Kala zone, which was already elevated at that time. This belt formed the

frontal fold of the Ezzet-Karagez zone. Corroboration is afforded by the great thickness of Neocene rocks, exceeding 1,000 m. Considerable folding in the Shakhman structure was proved by the seismographic method. As the result of the post-Akchagylian folding, including the Ezzet-Karagez zone, it became intensely dislocated, while the Shakhman fold continued to sink.

When all the West Kopet-Dag is considered, it can be included in the mega-anticlinorium as a deeply depressed flank in spite of very real differences of its structure as compared with the southern regions of Kopet-Dag. The differences in the history of development of these two large structural units correspond to the differences in their structure. But the undeniable fact that both structures were formed within the limits of one geosynclinal system makes it possible to consider them as different parts of one larger structure.

Northeastern Flank of Kopet-Dag Mega-anticlinorium

The next region to be described is located east of Ashkhabad and north of the boxlike structures of the South Kopet-Dag anticlinorium considered above. In that location is the folded zone of the northeast flank of the Kopet-Dag mega-anticlinorium. V.P. Miroshnichenko studied its eastern part and called it the North Kopet-Dag zone of folding [18]. We think this zone extends further to the northwest and includes the Gyaur anticline also. The latter is one of the largest structures of this zone. Together with the Zirakev anticline, to which it is linked, it extends over 75 km. from northwest to southeast. Gyaur anticline proper is a large brachy-anticlinal fold with a latitudinal direction, differing slightly from the general direction of Kopet-Dag. It is asymmetrical, with an overturned northern flank in which the movement of the Neocomian nucleus over Paleocene rocks can be observed. We believe that this covering of Paleocene rocks by the Neocomian nucleus should not be extended along all the northern flank of the fold, as P.I. Kalugin has done [6, 7]; it should be limited to the nucleus of the anticline.

South of the Gyaur and Zirakev anticlines the large brachy-anticline of the Ala-Dag ridge is situated. In its structure and size it resembles the Gyaur anticline; both have a latitudinal direction, i.e., different from the direction of South Kopet-Dag anticlinorium. The northern flank of the Ala-Dag anticlinal fold is overturned and broken by a large fault, along which Neocomian rocks have moved over Upper Cretaceous and Paleocene rocks. More to the east, along the border of the State, extends the anticlinal ridge of East Kopet-Dag, situated in the northern fringe of the zone discussed. The ridge consists of a number of brachy-anticlinal folds, forming a large anticlinal structure made up of rocks of Lower Cretaceous age. In the southeast there are also Upper Cretaceous rocks. East Kopet-Dag anticline has an asymmetric. Along the northern limit of the anticline, in places where the hinge of the fold rises and the Neocomian limestone comes to the surface, small, steep overthrust faults developed. In places where the hinge of the fold sinks, the overthrust faults are not observed.

The large Kelyatin syncline extends south of the East Kopet-Dag anticline. It is very wide, but its central part is flat, resembling the Donatin and Khodzha-Kala synclines of West Kopet-Dag. A few smaller folds extend to the southeast.

All the folded zone of the northeast flank of the Kopet-Dag mega-anticlinorium consists of a number of fairly large folds having in general a southeast strike and linked together. It is easy to see that the relationship of this zone with the South Kopet-Dag anticlinorium is similar to the relationship of the latter with West Kopet-Dag.

As was already stated, the folding of West (and East) Kopet-Dag is more recent than the folding of the South Kopet-Dag anticlinorium, which is situated more to the south. In West Kopet-Dag, pre-Miocene movements were almost absent and resulted in only a temporary elevation of this zone and insignificant erosion of the upper Paleocene horizons. Pre-Akchagylian folding was the most pronounced in West Kopet-Dag; at that time the main folded structures were formed. The regions of Central Kopet-Dag, south of Ashabad, were folded in pre-Miocene time and experienced only general elevation. In pre-Akchagylian time, apparently, the folds of the northeastern flank of the mega-anticlinorium also were formed. This cannot be proved because there are no Neocene marine deposits in that place. Ezzet-Karagez and to a lesser degree Aladag-Kulmach folded zones were formed even more recently, in the post-Akchagylian epoch.

FRONTAL FLEXURES

Pre-Kopet-Dag Frontal Fold

The frontal flexure extends north of the Kopet-Dag mega-anticlinorium. Considerable folding began here, possibly in the Upper Cretaceous, extending from the North Kopet-Dag zone of large Upper Cretaceous and

Paleocene folds situated more to the south and including the Ashkhabad region. The formation of the fold took place in the Neocene. Upward movement began at that time to the south of the North-Kopet-Dag zone. The Ashkhabad region was not included in this uplift. The migration of the regions of folding in a northerly direction was confirmed by seismographic studies. In deeper horizons the axis of the fold (top of the Paleozoic formations), is displaced toward the south with respect to the axis in Cretaceous and Tertiary rocks [4]. Geophysical investigations by Yu. N. Godin indicated that the Cis-Kopet-Dag fold is made up of three depressions separated by dikes. A major part of it is within the Ashkhabad valley, protruding far to the north. It is distinctly asymmetric: maximum depths, up to 4,000 m. to the top of the Cretaceous are found next to Kopet-Dag.

The Kazandzhik valley is situated more to the west, and is separated from the Ashkhabad valley by the pass in the region of Kizyl-Arvat. Here a protrusion of Mesozoic rocks is suggested by geophysical data. Even in the deepest part of the fold the Mesozoic rocks are found at a depth of 1,500 to 2,000 m. The Kazandzhik valley is smaller than the Ashkhabad valley and extends in the shape of a narrow belt along the frontal anticline. However, the depth of 3,500 m. to the top of the Cretaceous is approximately the same as that of the Ashkhabad valley. Near Bol'shoy Balkhan the valley terminates centroclinally. The synclinal zone of the Balkhan corridor can be considered as the southwestern continuation of the fold. This zone unites the Kazandzhik and Pribalkhan valleys.

The Kaakhkin valley, situated east of the Ashkhabad valley, is less pronounded. Its morphology is apparently similar to that of the Kazandzhik valley, except that it is shallower. To the east, in the Dushak region, the Kaakhkin valley, according to geophysical data, terminates centroclinally. This is also confirmed by the wide development on the left bank of the Tedzhen, more to the southeast of the Paleocene deposits, which dip sharply toward the western part of the flexure. Thus, at the eastern end of the Kopet-Dag mega-anticlinorium the frontal flexure is absent, and the mega-anticlinorium is in direct contact with the platform.

Recently, some data were obtained on the structure of deeper strata of the fold. According to seismographic studies [4] in the Kizyl-Arvat region, the top of the Paleozoic rocks in the fold is found at a depth of 8 km. in the shape of a sloping, almost symmetrical, trough. The axis of the trough is displaced southward with respect to the axis of the fold. The top of the Paleozoic in the Ashkhabad region gradually sinks in a southeastern direction to a depth of 9 to 10 km. Seismographic data also indicate a strong dislocation of the underlying Paleozoic rocks.

In isolated places along the southern fringe of the flexure, where it meets the Kopet-Dag mega-anticlinorium, are found small folds consisting of Neocene and, less often, of Paleocene rocks. These folds were formed in the post-Akchagylian epoch, but the largest of them, in the Kizyl-Arvat region, were formed in the Pre-Akchagylian epoch.

North El'burs Frontal Fold

A number of signs north of the El'burs mega-anticlinorium point to the existence of a zone of large Upper Tertiary and Quaternary folds. The folds are on a larger scale than those of the Keymir-Chikishlyar region to the north. From its structural position between the young folded region and large central massif, this zone belongs to the frontal folds. The existence of a fold here is indicated by the fact that south of the Keymir-Chikishlyar region, near the State border, the force of gravity decreases from north to south, indicating sinking of beds in this direction. Prospecting by electric methods indicates asymmetric synclinal formation of the Gorgan depression. The steep side extends along the foothills of the El'burs. The presence of a large valley is confirmed also by the thick Neocene and Quaternary formations on the northern slopes of El'burs. All these data indicate the existence of a large flexure in the southern part of the Transcaspian valley, which should be considered as the frontal El'burs fold.

The Superimposed Pliocene-Quaternary Fold of Kuchan-Meshkhed

A synclinal zone is situated between the Aladag-Binalud and Kopet-Dag mega-anticlinoria. The greater part of it belongs to the Kuchan-Meshkhed flexure. The syncline is filled with alluvial deposits of the Keshefrud and Atrek rivers. The flexure is situated at the contact of two tectonic zones of different structure and historic development. Consequently the composition of the flexure is not uniform; in the north it is composed of rocks of Upper Jurassic age, and granite appears from under the Quaternary deposits to the south. The granite outcrops in the Binalud ridge. According to A.F. Sosedko and P.I. Kalugin, a zone of large faults along the southern edge of the flexure separates Binalud from Kopet-Dag and vanishes in the east toward the Afghan border.

Because of the nature of its structure and iistoric development the Kuchan-Meshkhed valley should be included in the young folds leveloped from the sinking of parts of Aladag-3inalud and Kopet-Dag mega-anticlinoria. This flexure probably appeared only in the Pliocene, since older Tertiary deposits are iot observed here. More intense sinking of he fold took place in the Quaternary.

Region of Strong Mesozoic and Cenozoic Folding (Pribalkhan Valley)

The Pribalkhan depression is situated in he northern part of the Transcaspian valley. t is limited in the north by the Bol'shebalk-ian-Kubadag anticlinorium; by the folded structures of West Kopet-Dag in the east; ind in the south, according to geophysical lata, by the line marking the area of the argest decrease of gravitational force reaching 90 mgal. in the center of the val-ey) in the south. In the west the Pribalkhan lepression, after a slight elevation at the Cheleken meridian, extends to the central part of the Caspian Sea. The Pribalkhan lepression is divided into two valleys: Kel'korsk valley and Kyzyl-Kum valley. They re separated by an elevated zone containing he so-called Pribalkhan Neocene dome-like olds, broken by numerous small faults.

The characteristic property of the Pri-ıalkhan depression is that during the entire Mesozoic and Cenozoic it was a region of trong folding. The thickness of Cenozoic ocks in the Kel'korsk and Kyzyl-Kum flex-res, according to seismographic data, eaches 6 to 7 km. Mesozoic deposits are ven thicker. Thus, even in the western entrocline of the Pribalkhan depression, the op of the Paleozoic rocks is found at a epth of 14 km., rising steeply towards ol'shoy Balkhan and more gradually in the irection of West Kopet-Dag [4]. Yu. N. Godin believes that the Pribalkhan depression vas strongly folded also in the Upper Paleo-oic era [5]. The central part of the depres-ion is connected with the dome-like folds. udging from the decreased thicknesses, elative elevations in this region were formed nly in Pliocene times and during all the Quaternary period up to the present time. n Boya-Dag, according to A.A. Alizade, he terrace of Khvalin age is elevated 35 m. ompared with other regions of West Turk-ienia.

Parageosyncline of Bol'shoy Balkhan (Bol'shebalkhan-Kubadag Anticlinorium)

The isolated ridge of Bol'shoy Balkhan is ituated northwest of the Kopet-Dag mega-anticlinorium. Together with the low mountains near Krasnovodsk it forms one large anticlinal structure of the Bol'shebalkhan-Kubadag anticlinorium. Bol'shoy Balkhan is a large and wide (up to 40 km.), strongly elevated anticlinal fold, extending almost latitudinally over more than 100 km. Its sloping southern flank (dip 10 to 20°) consists of Neocomian and Malmian limestones and sandstones. The northern flank is made up of similar rocks together with Aptian and Albian, Upper Cretaceous and Paleocene rocks. It is much shorter and steeper with dip up to 80°. In places the strata are vertical or even overturned (dip up to 70° south). In the east, the Bolshoy Balkhan terminates periclinally. In the west, where the width of the anticline is greatest, sinking of rocks takes place in the central part and in the southern flank, while the northern flank extends to Belek. After a break, the Mesozoic formations are again observed near Krasnovodsk. Here the nucleus reaches the surface and also the steep northern flank of the second large anticlinal structure, Kuba-Dag.

Eruptive rocks appear in the nucleus anticline, separated by a fault. Such rocks are seen in the Shakh-Adam and Ufra peninsulas. There are a number of data indicating that Bol'shoy Balkhan and Kuba-Dag belong to one anticlinal structure. Both anticlinal formations extend in the same direction; their axial parts are in approximately the same latitude. Their type of section and general morphology of structure are similar. On the island Dag-Ada (between the two) porphyrite of the Krasnovodsk type is found transgressively with the basic conglomerate, usually covered by Malmian sandstones. The island is in the axial part of the hypothetical single structure. Finally, both structures are characterized by similar gravitational and magnetic anomalies, sharply differing in this respect from the Transcaspian valley. On the border with the latter, i.e., on the southern slope of the described structure, is the belt of maximum isoanomalic concentration, separating the positive gravitational field of Kuba-Dag and Bol'shoy Balkhan from the negative field of the Transcaspian valley. All this indicates that both structures constitute one complex anticlinal formation of anticlinorium type. The conclusion that Bol'shoy Balkhan and Kuba-Dag are parts of one anticlinal structure was reached by many geologists (N.P. Luppov, M.V. Muratov, Yu. N. Godin, B.A. Petrushevskiy, V.F. Solov'yev). Geophysical data (gravimetric and seismographic) indicate that the northern part of Krasnovodsk Bay and the Dardzha peninsula belongs to the Bol'shebalkhan-Kubadag anticlinorium. That area is now covered by Pliocene and Quaternary formations. The sharp change of the gravitational

field, characterizing the transition from the anticlinorium to the Transcaspian valley, is observed only 20 to 30 km. south of where Mesozoic rocks of Kuba-Dag appear on the surface.

The opinions of geologists concerning the structural relationship between Bol'shoy Balkhan and other regions diverge. Some of them, for example A. L. Yanshin [36], B. A. Petrushevskiy [25, 26], V. F. Solov'yev [31], and others, associate Bol'shoy Balkhan and the structures situated more to the north with the epi-Hercynian platform. P. I. Kalugin [6], M. V. Muratov [19, 20], D. V. Nalivkin [22] and in part, N. P. Luppov [14], include it in the Alpine geosynclinial region. The author of the present paper has recently come to the conclusion that the second point of view is more correct. Geophysical and geological data in favor of both points of view are quoted. However, it should be emphasized that exhaustive geophysical investigation of this region indicates that the positive gravitational field of the Bol'shebalkhan-Kubadag anticlinorium is very similar to the gravitational field of the more northern regions of the platform [5, 34]. Seismographic data [4] indicate that the Bol'shot Balkhan region and the more northern regions of the platform are associated with areas where the Earth's crust is less than 30 km. thick, while in West Kopet-Dag (Malyy Balkhan and Kyuren-Dag) the thickness of the crust increases to 40 km. and more. Only relatively small decrease of the gravitational field values is observed north of Bol'shoy Balkhan. The increase corresponds to the synclinal structure which is present here. Thus the geophysical data indicate the similarity between the structures of the deep parts of the regions of Bol'shoy Balkhan, Kuba-Dag, and the northern part of the platform. In our opinion, however, the geophysical data cannot be considered as sufficient basis for correlating Bol'shoy Balkhan with the epi-Paleozoic platform. We should remember that the Upper Crimea region and West Caucasus also have positive gravitational field values, which are often characteristic for platform regions. The separation of Crimea or Caucasus into tectonic regions is carried out on the basis of the present day structure and Meso-Cenozoic history of these regions. The same procedure should be used in the case of Bol'shoy Balkhan.

The Alpine stage of development of Bol'shoy Balkhan began with the formation of a large intrageosyncline consisting of Jurassic rocks only, and having a thickness of 4500 m. At that depth the bottom of the Jurassic section is not yet reached. With respect to the character of the folding movements in the beginning of the Alpine cycle, causing strong flexing in the Jurassic period and uplift in the beginning of the Cretaceous, Bol'shoy Balkhan resembles other geosynclines of the Alpine zone (Caucasus, El'burs and Ala-Dag). While the axial parts of the Caucasian and El'burs - Ala-Dag intrageosynclines ceased to fold since the Lower Cretaceous, the Balkhan intrageosyncline was more mobile and was considerably folded in the Lower Cretaceous. In the Upper Cretaceous and in the Paleocene the folding gradually ceased. Thus the Bol'shoy Balkhan intrageosynclines, as compared with other intrageosynclines of the Alpine geosynclinal zone, was flexed in the same way in the beginning of the cycle. In more recent times it proved to be even more mobile.

When considering the structural problem of Bol'shoy Balkhan some authors emphasize, for example, the thinness of Cenozoic deposits in Bol'shoy Balkhan [25, 26], and consider this as a proof of the platform nature of its development at that time. This is due to a misunderstanding. We should compare the Bol'shoy Balkhan section with parts of a geosyncline section which developed in the same way; in this case with the central part of the Caucasian mega-anticlinorium, the Somkhet-Karabakh zone of Lower Caucasus, and with the axial part of the El'burs mega-anticlinorium. All these zones are characterized by a sharp decrease in thickness of the Cretaceous, and in the Paleocene and Neocene they were already elevated. However, the strong flexing in Cretaceous and Lower Tertiary epochs occurred there independently of this elevation. In Bol'shoy Balkhan new zones of folding were not formed on the periphery of the elevation. Here the undulating movements were different, consisting of general elevation in the Neocene and in gradual weakening of folding in the Cretaceous and in the Paleocene. By comparing the thickness of rocks in various geosynclinal zones it is possible to show, for example, that in the Cretaceous and Paleocene, Bol'shoy Balkhan was folede several times more intensely than the other geosynclinal provinces. Thus the Lower Cretaceous rocks in West Kopet-Dag are three times thinner than in Bol'shoy Balkhan; the Lower Cretaceous rocks in North Caucasus are half as thick as those in Balkhan.

Let us now consider the age of folding in Bol'shoy Balkhan. After relatively weak movements on the border between the Jurassic and Cretaceous [15], the present day folded structure of Bol'shoy Balkhan formed, as in the Kopet-Dag mega-anticlinorium, mainly in two phases: pre-Miocene and especially pre-Akchagylian. As in Kopet-Dag, strong levelling movements began in post-Akchagylian time. The geologists who associate Bol'shoy Balkhan with the platform usually disregard the fact that the momen-

tum of Pliocene and Quaternary movements of Bol'shoy Balkhan is commensurate with the elevations of central Kopet-Dag (2,000 m.) and is twice as intense as the elevation of most of the western Kopet-Dag. Quite a different picture is presented by Tuar-Kyr, which is characterized by the platform type of later movements.

The present day structure of Bol'shoy Balkhan differs radically from the structure of the Meso-Cenozoic part of the more northern regions. It is true that its structure is simple. Here there is no such complex folding as, for example, in the axial part of the Caucasus or in Ala-Dag. It should be remembered, however, that in most regions of the Alpine geosynclinal province, consisting of rocks of the same lithologic composition (i.e., areas where compact limestones of the Upper Jurassic and Neocomian predominate) we often encounter even simpler folded forms. Thus, the entire western part of the South Kopet-Dag anti-clinorium consists of very simple and sloping folds. The same can be observed in many regions of Upper Crimea. When compared with these examples the structure of the Bol'shebalkhan-Kubadag anticlinorium with its steep and often overturned northern flank is much more complex. The similarity to Crimea is made more pronounced by the presence of a deep zone, separating Bol'shoy Balkhan from the South Caspian valley (situated more to the south). Recent seismographic observations [1] indicate the presence here of a focal surface, which dips under the Bol'shoy Balkhan. As in the Crimea, the depths of the earthquake foci reach here 40 km., i.e., the bottom of the Earth's crust. The data on the age of eruptive rocks [25] are not convincing enough for the corroboration of any of the theories, since the eruptive rocks of Krasnovodsk and Bol'shoy Balkhan are little known, and the opinions of geologists working here are divergent. But even if the rocks were of Paleozoic origin, as rightly noted M. V. Muratov [20], it would not be an argument for associating the region with the platform. Paleozoic and even Pre-cambrian rocks are often developed in the axial parts of large Alpine anticlinal formations. Western Caucasus and Ala-Dag are examples. Thus, when we consider the character and age of the folding, the intensity of the more recent uplifts, and the morphology of the folded structures, we can see the basic difference of Bol'shoy Balkhan from the platform structures such as Tuar-Kyr, which are situated farther north. At the same time we should always note the structural features and historic development which are similar to those observed in Alpine geosynclines.

Noting, however, the basic similarity of the Alpine stage of development of the Bol'shoy Balkhan-Kubadag anticlinorium with other Alpine formations, the more interesting differences which distinguish Bol'shoy Balkhan from other Alpine formations should not be disregarded. The folds of the Bol'shoy Balkhan are characterized by the fact that here, unlike in the Caucasus or the Turkmen-Khorasan mountains, there was no subsequent migration of folds in a direction away from the uplift appearing at the beginning of the Alpine cycle. After strong folding in the Jurassic period and temporary elevation and erosion before the lower Cretaceous, folding occurred again and then gradually ceased in approximately the same places. This type of undulating movement, not followed by partial inversion, is characteristic of parageosynclines. The properties of the parageosynclinal development of Bol'shoy Balkhan are probably due to the fact that the Jurassic flexure was formed in the place of an old epi-Paleozoic platform. This hypothesis is corroborated by the similarity of structure of deep zones situated under Bol'shoy Balkhan and in the more northern regions.

Considering the tectonic nature of Bol'shoy Balkhan, it should be remembered that we can deal with two histories of its structure -- ancient (Paleozoic), and modern. There are data, predominantly geophysical, indicating that in the Upper Paleozoic era the Bol'shoy Balkhan-Kubadag anticlinorium formed a part of the territory characterized by platform structure. However, during the Alpine stage this regions was involved in folding. Its present structure is that of a typically Alpine formation and therefore should be included in the Alpine geosynclinal province.

Central Massifs

Iranian Central Massif

The large Iranian central massif is situated south of the Turkmen-Khorasan mountains. Isolated large anticlines, generally continuing the folded structures of El'burs and Ala-Dag - Binalud mega-anticlinoria, rise among the flat northern expanses of the Desht-i-Kevir desert. Their nuclei are often formed by Paleozoic rocks, sandstone-shale strata, or by Upper Cretaceous rocks which cover them non-conformably. The flanks usually consist of Miocene salt-bearing gypsum.

During the greater part of the Alpine stage of development, this territory was elevated, and only during the time of great transgressions was it covered by the sea. Intense folding began only in the Miocene, predominantly along the southern edge of the Turkmen-Khorasan mountains. Thus, in the Semnan and Ahakhrud region, south of El'burs, the thickness of Miocene rocks exceeds

3,000 m. [38]. In the Pliocene the folding was probably weaker.

Little is known of the time when the base of this massif formed. Studying the structure of the Iranian plateau in the Anarek region (slightly south of the edge of the map) E. Baier [36] concluded that a considerable part of the strongly dislocated metamorphosed rocks, earlier referred to the Paleozoic era, is in fact Liassic and indicates intense post-Liassic folding. Considerable areas of the Iranian central massif are probably even older. The formation of the anticlinal structures developed in the upper part of this massif, took place mainly in the Miocene.

Central South Caspian Massif

Geophysical data indicate several large structural units in the Transcaspian lowlands. The southeastern part of the lowlands, taken up by the continuation of the folds of the Kopet-Dag mega-anticlinorium, are transgressively covered by Pliocene and Quaternary deposits. The Transcaspian valley proper begins only farther west, where the thickness of Pliocene-Quaternary rocks reaches 2,000 to 3,000 m. According to seismographic data, the top of the Cretaceous is at the depth of up to 7 km., i.e., twice as deep as in the Cis-Kopet-Dag flexure. Several large structural units can also be isolated within the limits of the deeply depressed part of the Transcaspian valley. For example, the Shakhman Neogene flexure, which can be considered as the frontal fold, developed northwest of the now hidden folds of the Messerian-Khodzhakala zone. Farther the Transcaspian valley should be divided into three large tectonic units: Pribalkhan depression; old, deeply sunk, Keymir-Chikishlyar massif; and North El'burs frontal fold.

The large Keymir-Chikishlyar field of relative gravitational maximum (10 to 25 mgal.) is situated in the central part of the Transcaspian valley. Having the shape of a large rectangle, it continues into the Caspian sea in the west. The local Ala-Dag gravitational force maximum, corresponding to the Messerian-Kodzhakala zone, originates in its northeastern corner. According to seismographic data, the Tertiary and Quaternary formations here reach the depth of 6 to 7 km. Below them are weakly dislocated and strongly compressed Mesozoic formations, under which, at the depth of about 10 km. (according to Yu. N. Godin's calculations) is the Paleozoic basement. The structure of the Keymir-Chikishlyar region rests on an old base[1] upon which the rocks are distributed horizontally and in places form monoclines. It resembles the structure of the platform, but the upper stages are considerably thicker (6,000 to 8,000 m. and in places, perhaps even more).

In the upper (Neocene) strata of the Keymir-Chikishlyar region there are developed quite different folds than the Pribalkhan ones. They are large and sloping brachy-anticlines, separated by synclines of equal size. Together they form a large tectonic zone having meridional direction.

The Platform. (Tuar-Kyr mega-anticline)

North of the Turkmen-Khorasan mountains and the Bol shoy Balkhan there are two large and very strongly folded mega-anticlines. The Tuar-Kyr mega-anticline consists of Jurassic, Cretaceous and Paleocene rocks. The steepest dips are observed in Jurassic and lower Cretaceous rocks (10 to 15°) and in the upper beds they often cannot be observed even by means of a compass. The region of pre-Jurassic rock development (dip up to 90°), related to the lower structural stage of the platform, appear on the background of these mild dislocations. The Tuar-Kyr mega-anticline plunges toward the southeast, and according to the gravitational anomalies, it extends over a considerable distance after its visible termination. The smaller Goklenkuyusinsk anticline, also extending far to the southeast, is situated to the east. The contours of these structures are shown on the tectonic map of Yu. N. Godin.

The presence of the intensely dislocated pre-Jurassic basement in Tuar-Kyr region and the thin, sloping blanket of rocks indicate that north of the Alpine geosynclinal region there is a young epi-Paleozoic platform. According to M. V. Muratov [21], it can be considered as a part of the Skif platform.

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Concluding the description of the individual tectonic zones, singled out within the Turkmen-Khorasan mountains and neighboring

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[1]It is very probable, that here the Precambrian basement is near the surface. This is partly confirmed by the decrease of the thickness of Paleozoic rocks in this direction 4, 5 .

territory, it should be emphasized that although each of them has its own history of development, age of folding and morphology of the folded structures, there is a close relationship between them. The formation of each such zone represents only a definite stage in the general development of the Turkmen-Khorasan geosyncline. Strong flexing within the limits of the El'burs-Aladag-Binalud zone began in the Jurassic period, and then migrated to the region of the southern Kopet-Dag anticlinorium in the Lower Cretaceous period. Uplift began in the Upper Cretaceous period and the regions of folding were displaced further north toward the northern Kopet-Dag zone. Finally, the formation of the Pre-Kopet-Dag frontal fold in the north, and the Shakhman flexure in the west took place in the Neocene and Quaternary periods. Analogous history is observed also in the El'burs mega-anticlinorium.

The migrations of the folding phases follow the flexures, spreading from the central parts of the mountains toward their periphery. Each of the separated tectonic zones represents a specific type of folding, but in general all the simpler folded forms can be observed in passing from the regions of older, to the more recent folding.

The most pronounced depression in the central massifs and the neighboring platform regions, which earlier were relatively elevated, took place in the Neocene and the Quaternary periods, during the most intense uplifts in the mountainous regions. Valleys, which were elevated for a long time, formed in the oldest regions of the folded formation during the final stage of geosynclinal development.

The Pribalkhan valley and the Bol'shoy-Balkhan-Kubadag anticlinorium differ somewhat from the fluctuating development of the geosyncline. The latter was intensely folded during the whole of the Alpine cycle.

The region of the Bol'shoy Balkhan and Kuba-Dag was intensely folded in the Jurassic period; in Cretaceous and Paleocene times the folding gradually ceased and then was replaced by uplift. In both zones there was no consecutive spreading of uplift and migration of flexures. Such structural units with incomplete development should be considered as parageosynclines.

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Institut Fiziki Zemli,
Akademiya Nauk SSSR, Moskva

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GEOLOGIC DEVELOPMENT HISTORY OF NORTH KHARA-ULAKH

by

A. A. Mezhvilk

ABSTRACT

This paper attempts to review the geologic history of North Kham-Ulakh in the light of new data obtained as the result of a geologic survey on the scale 1:200,000.

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Until recently, incomplete data on the geology of North Khara-Ulakh led to very different interpretations of the history of its folded structures [1-4, 6-14]. Stratigraphic work carried out by geologists of the Research Institute of Geology of Arctic Regions at the mouth of the Lena River in recent years, makes it possible to improve considerably our knowledge of the development of the region.

In the territory extending from the mouth of the Lena to the Laptevykh Sea, between the latitudes 72°30' and 71° north, there are the following tectonic structures (from west to east):

1. The Olenek uplift consisting of flat-lying Cambrian rocks (Cm) with small intrusions of metamorphic and eruptive Proterozoic rocks in river valleys (Solooli River). The uplifted block is encircled on three sides by Mesozoic formations (TR, J, K).

2. The Lena flexure, filled with Permian, Triassic, Jurassic and Cretaceous formations exposed (adjacent to the platform) in a large asymmetrical syncline, having steep eastern and western flanks (see map).

3. The Khara-Ulakh anticlinorium of the first order consisting of:

(a) West Khara-Ulakh anticlinorium (Khara-Ulakh protrusion of the lower Paleozoic base of the flexure [10], that consists of two somewhat asymmetrical folds (Bulkur and Kengdey), having a meridional trend with the core consisting of lower Paleozoic rocks. These anticlines are separated by the Tasarin syncline, filled with Permian, Triassic, Jurassic and Cretaceous deposits.

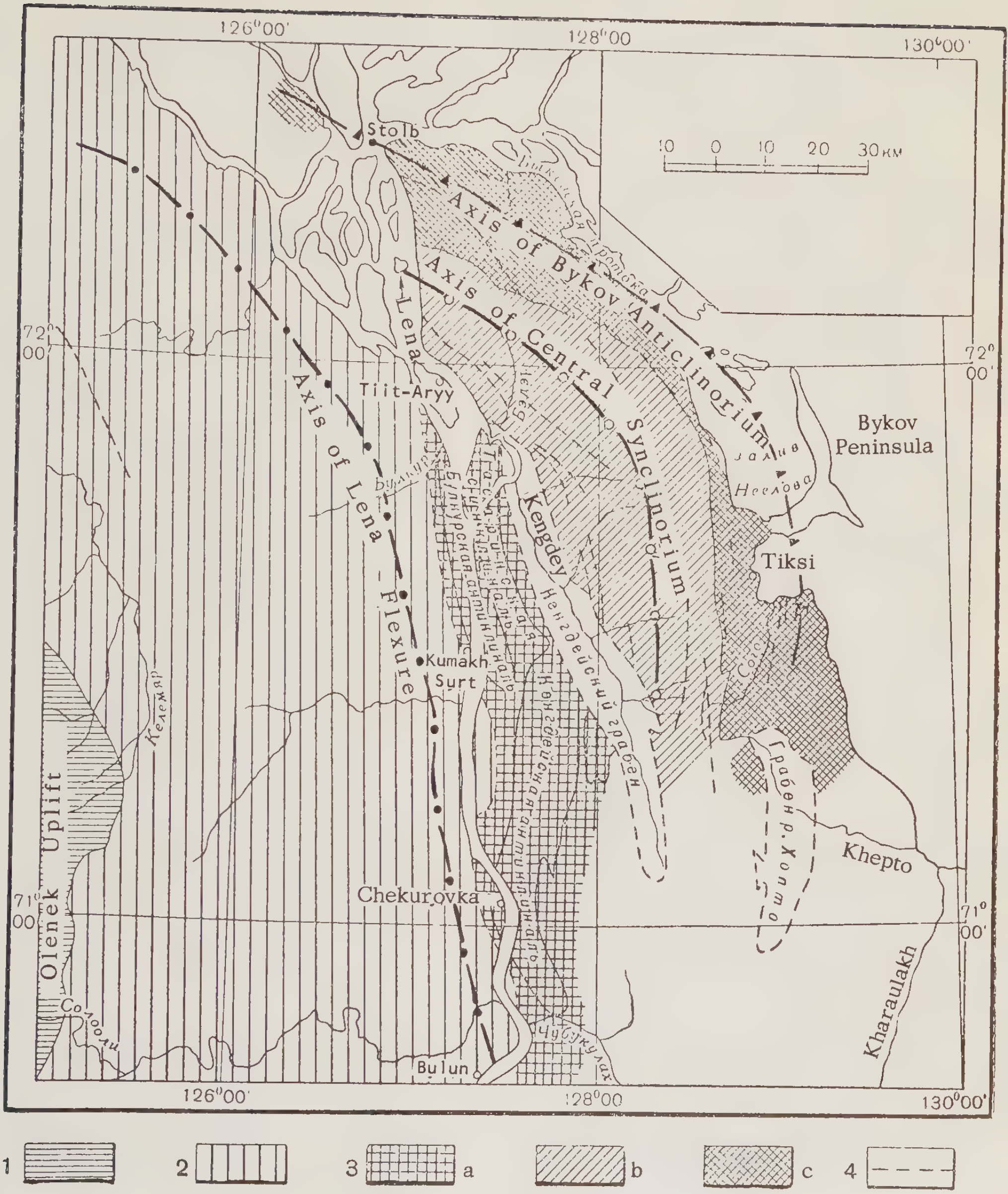
(b) The Central synclinorium, a complex synclinal structure consisting of linear folds with overturned flanks, containing upper Paleozoic, and, in the axial part, Triassic rocks. At the latitude of Tiit-Aryyn village, the meridional trend of the synclinorium changes to northwest. The synclinorium narrows in this direction and at the mouth of the river Olenek it becomes even more narrow, and possibly terminates.

(c) The Bykov anticlinorium, consisting of Silurian, Devonian, Carboniferous and Permian rocks, intensively faulted into tectonic blocks.

The study of the relationship between various series, stratigraphic units, lithologic facies, and structures of the region makes it possible, with some assumptions, to outline the following history of geologic development in this region.

Accumulation of thick terrigenous sediments took place during the Proterozoic era. These deposits were folded, the folds having a northwest trend. In the outer zones of the region basic and acid rocks were intruded. At the end of the era the folded formations constituting the territory were intensively eroded, and the mountains were levelled. The accumulation of conglomerate and sandstone, which is exposed in the northern part of the Anabar massif, probably occurred at that time.

In Sinisian time the northeast part of the Siberian plateau was considerably lowered, and a transgression of the sea across the



Outline of the tectonics of North Khara-Ulakh.

1 - Olenek uplift; 2 - Lena flexure; 3 - Khara-Ulakh anticlinorium of the first order: a) West Khara-Ulakh anticlinorium, b) Central synclinorium, c) Bykov anticlinorium; 4 - tectonic displacements.

levelled surface took place. During this time, the accumulation of carbonate sediments containing seaweed and spores occurred. Smaller amounts of terrigenous clastic sediments were also deposited. The present thickness of these deposits is greater than 700 m. During sedimentation, slow folding movements took place, which led to breaks in the deposition of sediments and to the formation of conglomerates.

During the Cambrian period, non-uniform flexing of this part of the Earth's crust, and accumulation of carbonate sediments, took place. During Cambrian time the basin was populated by trilobites. The Aldan epoch of the Cambrian period was characterized by the transgression of the sea over the flat-lying, differentially eroded, Sinisian formations. At the beginning of Aldan time, terrigenous deposits, later replaced by carbonates, were deposited.

In the Lena and Amgin epochs, bituminous sediments and marl were deposited; in the Maisk epoch marl was deposited; and in Upper Cambrian time, sand mixed with lime was deposited. The present stratigraphic sequence indicates a generally repeated cycle of sedimentary deposition.

The transgression reached its maximum extent between Lower and Middle Cambrian time, when bituminous sediments accumulated in the vast territory of the Siberian plateau. At that time North Kara-Ulakh was raised 1,000 m. above the Olenek uplift.

Between the Cambrian and Ordovician rocks, in the territory of North Khara-Ulakh, there appeared a plunging anticline, which was subsequently eroded down to its Lower Cambrian rock. As the result, Ordovician sediments were deposited, with a stratigraphic hiatus, parallel to Middle Cambrian rocks in the Olensk region, and parallel to various divisions of the Cambrian in Khara-Ulakh. In pre-Ordovician time, apparently, the intrusion of gabbro-diabase sills took place; numerous boulders of these igneous rocks are found in upper Paleozoic rocks at the mouth of the Lena River [5]. The intrusions do not involve Ordovician formations, even though they occur near Cambrian formations.

The Ordovician and Silurian periods were characterized by the subsidence of this part of the Earth's crust and by transgression and accumulation of dolomite and to a lesser degree limestone, having a total thickness of about 1,400 m. In the Ordovician period, dolomite (800 m.) was deposited in an open marine basin, where there was no influx of terrigenous material within the limits of North Khara-Ulakh, and the conditions were unfavorable for the preservation of fossils.

In the Llandoverian time, the conditions of sedimentary deposition were still the same, but corals appeared. During Wenlock time, bituminous limestone accumulated, and in Ludlow time, limestone of organic origin, containing crinoids, was deposited. It appears that the latter are sediments characteristic of shallow, warm seas, far from the shore. The transgression in the beginning of the Ordovician period, was followed by regression at the end of the Silurian period.

No Lower Devonian deposits survived in North Khara-Ulakh, and therefore the paleographic conditions of that time are not clear.

In the Middle and Upper Devonian era the territory of the North Khara-Ulakh subsided again and underwent another marine transgression. Bituminous carbonate deposits of Middle Devonian age, containing the remains of stromatoporoids, were succeeded by dolomite, dark-gray limestone and marl with abundant brachiopods. The presence of carbonate deposits about 800 m. thick and the absence of clastic beds suggest the presence of a large, warm Devonian sea. The contamination of the deposits with clay, and the increase in the number of individuals in the fossil fauna toward the upper part of the sequence indicate that the Devonian sea was becoming smaller and shallower.

Between the Devonian and Carboniferous periods, the territory underwent folding, which caused the erosion of Devonian, Silurian and some Ordovician rocks of the Olenek uplift. In the Khara-Ulakh only Famennian and some Fransian deposits were eroded; as a result the Carboniferous rocks lie on Upper Cambrian rocks in the west and on a Fraksian layer in the east.

During early Carboniferous time a new subsidence of the territory was followed by a large transgression of the sea, extending over all the Siberian plateau. In the North Khara-Ulakh, shallow, terrigenous deposits of high carbonate content accumulated (200 m. thick); these deposits were gradually succeeded by marl and then by pure limestone (300 m. thick) with an abundant fauna of corals and brachiopods. In Visean time crinoidal limestones were deposited interbedded with clay (thickness 100 m.). The character of the deposits indicates that the maximum extent of the transgression occurred at the end of the period, when the terrigenous material ceased to flow to the North Khara-Ulakh region. The folding in Early Carboniferous time was somewhat more pronounced here than in the Olenek region, where the remnants of the deposits of that age are thin (200 m.).

We conclude that during early and Middle

Paleozoic time, in the North Khara-Ulakh territory, as in the northeastern fringe of the Siberian plateau, predominantly undulatory movements affected the platform; this was followed by the accumulation of carbonate sediments. All this supports the view of N.P. Kheraskov [12] and others, who believe that the Siberian plateau, up to and including Early Carboniferous time, was much larger than today. The somewhat increased folding of the North Khara-Ulakh at that time, as compared with the Olenek region, is reflected by similar folding in the central part of the Siberian plateau. However, in the North Khara-Ulakh, the more intense movements took place during upper Paleozoic time.

In post-Visean time the territory corresponding to the present day Khara-Ulakh mountains, including the neighboring regions to the north and east, were affected by immense tectonic dislocations, which divided the plateau into blocks. Some of them were lowered and others strongly uplifted and eroded. This assumption is confirmed by the character and distribution of the terrigenous deposits of the upper Paleozoic.

In Middle Carboniferous time, simultaneously with the development of horst mountains and erosion of Lower and Middle Paleozoic rocks, the Earth's crust was subsiding along the faults which coincide with the direction of the present-day folded structures within the limits of the present-day delta of the Lena River and the eastern part of the Laptevykh sea. At the foot of the mountains "molasse" accumulated, and farther still, under littoral marine conditions -- sand and clay deposits 500 m. thick were deposited. Non-uniform subsidence of the blocks was reflected in the character of their contact with the underlying rocks, which are parallel to either Silurian or Visean rocks.

The Upper Carboniferous deposits lie on the eroded surface of various facies of the Atyrdakh suite. They are represented by bituminous, clay-bearing rocks, and siltstones, up to 800 m. thick (Tiksin suite). It appears that coarse detritus was not deposited because of the complete denudation of the source of sediments and the recession of the shores. The deposits contained brachiopods, corals, trilobites, goniatites and foraminifera. Carbonate rocks were formed in small quantities. Abundant plankton developed in the sea and was the source of organic material in the sediments.

Marine deposits of that time, obviously should not be thought of in terms of their present-day appearance, as is done by some authors. Judging from the presence of stratigraphically equivalent, analogous rocks in central Verkhoyan, the Late Carboniferous sea extended far to the south of the territory discussed, and probably extended far into the Siberian plateau.

Between the Carboniferous and Permian periods the North Khara-Ulakh territory was broken by major tectonic fractures, coinciding with the western border of the central synclinorium (approximately along the river Kengden). West of the Kengdei River, as the result of the uplift of the Siberian platform at that time, the formations of the Upper (?), Middle (?) and Lower Carboniferous and Devonian systems were destroyed. Permian deposits in this region were lying unconformably upon dolomitic Ordovician rocks. East and northeast of the Kengdei River, the territory was subsiding at that time, consequently, all the older formations were preserved. Lower Permian rocks lie here on Upper Carboniferous formations. The amplitude of the regional fracture, which later separated the folded Verkhoyan region from the platform, was not less than 1.9 km.

The Permian period was characterized by non-uniform subsidence of this part of the Earth's crust, by transgression and accumulation of terrigenous deposits, containing a large number of brachiopods and pelecypods distinct from Upper Carboniferous types.

The different thickness of the Permian deposits east and west of the Kengdei River indicates that the subsidence of these regions was taking place at different rates. The fracture which appeared in pre-Permian times continued to exist until the end of the Permian period and its amplitude reached 4 km. The change of facies from siltstone in the Lower Permian, to sandstone and siltstone in the Upper Permian, and the presence in the latter of shallow water deposits indicate that the basin decreased in size toward the end of the Permian period. Intraformational erosion was caused by tectonic movements during sedimentation, caused a temporary drying of the sea bottom.

Thus, the upper Paleozoic flexure, 30-60 km. wide, existed from the end of the Early Carboniferous time until the end of the Permian. It was filled with terrigenous deposits and "molasse", similar to the present-day Central synclinorium and Bykov anticlinorium. In pre-Triassic time, the rocks in the flexure formed plunging folds, which were partly eroded. West of this flexure (West Khara-Ulakh anticlinorium and Olenek uplift) the Permian formations remained undisturbed.

Magmatic activity at the end of the Permian period, which affected all of the Siberian plateau, caused the intrusion of trap-rock dikes having latitudinal direction in the

North Khara-Ulakh.

The Triassic sea transgression extended to the discussed territory only in the second half of Early Triassic time. By that time, the Permian fauna was extinct, and a new, abundant Triassic fauna appeared.

The same deposits (lower -- clay, upper -- sand) having the same thickness (T_1 = 100-150 m.) were formed both in the North Khara-Ulakh and in the Olenek uplift during Early and Middle Triassic time. Such conditions of deposition could only exist with simultaneous and similar minor subsidence of these different structural regions. At the end of Middle Triassic time, the sea regressed, the land uniformly rose above sea level, and as a result, the deposits of the Charnian transgression were deposited parallel to the eroded surface of Middle Triassic rocks. Regressive facies of the Late Triassic sea did not survive. Available data indicate that during the Triassic period, the North Khara-Ulakh and the Olenek uplift were subjected to two marine transgressions, which were due to undulatory movements affecting the platform. Between the Triassic and Jurassic periods, the western part of the territory was uplifted more than the eastern part. Denudation continued throughout the Early Lias and, consequently, the deposits of Middle Lias age were placed on all the older rocks extending toward the platform. Thus, at the mouth of the Kengdei River they lie on Charnian rocks, along the Lena River -- on Anisian rocks, in the Olenek uplift -- on Lower Triassic rocks, and at the latitude of Bulun village -- on Middle Cambrian rocks. The strike of the sedimentary layers is parallel, which indicates epeirogenetic uplift here at that time. During Middle and Late Lias and Aalen time, clay was deposited, which during the Middle and Upper Jurassic was succeeded by sand. Total thickness of these deposits is not less than 500-600 m. Judging from the thickness of the deposits, the flexing throughout the territory in the Jurassic period, as in the Triassic era, was of uniform platform type.

Between the Jurassic and Cretaceous periods, due to tectonic movements, the formation of the Tasarin syncline and probably the formation of new plunging folds, complicating the old ones, began east of the Kengdei River in the region of the Upper Paleozoic flexure. In consequence of these movements, Cretaceous beds were deposited around the Olenek uplift on Middle and Upper Jurassic rocks, and in the Tasarin syncline -- on Lower Jurassic rocks. Apparently, east of our territory, in pre-Cretaceous times, uplifts were taking place, followed by the extrusion of acid effusives which formed the shingle of Tuora-Sis ridge.

Unlike some authors, we believe that in Early Cretaceous time, the North Khara-Ulakh and Olenek uplifts were covered by a sea containing abundant aoucella. The lower part of the marine deposits consisted of clay and silt, which was succeeded in the upper part by sand and higher in the sequence gradationally replaced by coal containing parallitic formations. The accumulation of the latter, judging from the change of the continental and marine beds, was taking place on the plain, near the shore during Early and part of Late Upper Cretaceous time. In the Cretaceous period, the subsidence of the upper Paleozoic flexure was continuing over a greater area than the Olenek uplift, as indicated by the increasing thickness of deposits from west to east. For example, Valanginian rocks are 100 to 150 m. thick in the west and 400 to 500 m. at the edge of the upper Paleozoic flexure.

In the Late Cretaceous time, overturned folds and overthrust faults were formed by intense tectonic movements. At that time, the formation of the Tasarin syncline, with its overturned eastern limb, was completed. The Lena flexure, with its asymmetrical, synclinal structure was formed. This folding involved Upper Cretaceous rocks. Within the limits of the present-day Khara-Ulakh mountains, Mesozoic formations, covering the folded base, were elevated and destroyed by erosion. From the character of the deformation, it is obvious that the folding was due to tangential movements in the direction of the Siberian platform, from the east and northeast.

Intense uplifting in Late Cretaceous time were followed by a relatively long period of quiescence and peneplanation of the territory in pre-Danian time. The territory was at that time covered by coal-bearing rocks, which were non-conformable with the underlying formations.

During Paleocene time deposition of sediments and coal beds occurred, beginning in Danian time and continuing until the end of the Oligocene. In North Khara-Ulakh clay was the predominant type of sediment being deposited, and the conditions were favorable for the formation of coal (low relief, warm climate, etc.). The flexing of the territory was slow and affected certain blocks differentially. Some of them, for example, the Kengdei block, were rapidly subsiding, permitting the accumulation of thick deposits (1, 300 m.) and the formation of numerous, thin layers of coal. Along the Sogo River, the flexing was even slower. There, the sedimentary deposits were only 150 m. thick, but one 19 m. thick coal layer, almost free of mineral impurities, was formed. The fact that the Lower Tertiary deposits consist

exclusively of clay indicates a very limited influx of terrigenous material into the North Khara-Ulakh region, and it indicates further low relief in the detrital source area.

The second half of the Tertiary period and the Quaternary period were characterized by intense, differential, tectonic movements, followed by considerable displacements of blocks, and by dislocation of Paleocene coal formations. The dips of the coal layers in Kengdei range between 15-20°, and in Bykov channel 35-45°. In Recent time, uplifting of the individual blocks (Tuor-Sis ridge) is so intense, that erosion is much slower than uplift. All this indicates that the present-day relief was formed during Neocene and Quaternary time.

The above data lead to the following general conclusions:

1. The North Khara-Ulakh territory and the edge of the Siberian platform experienced thirteen major marine transgressions during the Paleozoic, Mesozoic and Cenozoic eras.

2. The character of the tectonic movements changed often. In the Early and Middle Paleozoic time predominantly undulatory movements of platform type occurred, which were followed by the accumulation of carbonate deposits. During late Paleozoic time differential movements of large amplitude occurred. At that time, the Upper Paleozoic flexure, filled with terrigenous deposits was formed. During the Triassic, Jurassic and Lower Cretaceous periods, North Khara-Ulakh experienced mainly undulatory movements, which also affected the edge of the Siberian plateau.

3. After Early Carboniferous time, the platform was replaced by the late Paleozoic geosyncline, the formation of which was accompanied by deep fractures.

4. During late Cretaceous time, due to plicative dislocations, the folding spread towards the west at the expense of the platform.

5. The deposition of rocks in the early Transgressive stages in the early Permian, early Triassic, early Jurassic and early Cretaceous periods is characterized not by coarse-grained beds, as it is generally assumed, but by fine-grained, clay-bearing formations, which during the regressive phase were succeeded by coarse-grained formations.

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AN EXAMPLE OF PLASTIC DEFORMATION OF LIMESTONES IN TECTONIC FRACTURE ZONES

by

G. G. Kravchenko

ABSTRACT

In the area of the Kansk polymetallic deposit (southwestern part of Kirghiz SSSR) there is widely distributed Lower Carboniferous limestone (Visean stage), containing numerous fragments of serpentinite. The limestone containing these fragments, that is, the limestone-serpentinite dikes, occurs as linear zones in serpentine rocks. Mapping and study of their structural details led to the conclusion that these formations originated during the process of plastic flow of the limestone in the tectonic fracture zones.

* * * * *

Main features of the geologic structure of the region.

The Kansk deposit is situated on the northern flank of a large anticlinorium, which has a latitudinal direction. It is a folded structure, complicated by a series of latitudinal fractures, dipping steeply to the north and south.

The oldest sedimentary rocks of the region, which developed in a latitudinal direction, are Upper Silurian multi-colored shale, sandstone and limestone. These rocks outcrop south of the deposit in the central part of the anticlinorium. The Upper Silurian beds which are up to 2,500 meters thick, are covered in places, nonconformably, by limestone, sandstone, shale and conglomerate of Lower, Middle, and Upper Devonian age. They appear mainly in the southern flank of the anticlinorium. In the northern part of the region the Devonian formations appear in the plain of the Kansk deposit. The thickness of the Devonian exceeds 2,000 meters. Higher in the section there are non-conformable Carboniferous rocks, the lower part of which is represented by 1,000 meters of Visean limestones. These rocks are widely distributed in the southern flank of the anticlinorium and in the plain of the Kansk deposit, where they are much less common. The Visean formations are conformably overlain by 700 meters of limestone, shale and sandstone of the Namurian stage, which are found in the southeast and east of the Kansk deposit. Higher in the section there is a more than 2,000-meter-thick series of Middle Carboniferous sandstone, shale, limestone and conglomerate.

The section terminates with a series of Mesozoic rocks about 900 meters thick containing clay, limestone, sandstone and conglomerate. These rocks are distributed mainly in the northern part of the region -- north and south of the Kansk horst.

Intrusive magmatic rocks connected with Variscian movements are not very common in the southern and northern parts of the region. They appear as two belts in latitudinal direction, 18 kilometers apart. Ultrabasic and basic rocks predominate among the magmatic formations. Rocks of medium, acid and alkaline composition are much less common, and appear mainly in the northern belt. The latter form a valley, of Alpine times. The horst, 25 kilometers long from west to east, and one-half to four and one-half kilometers wide, contains the ore bodies of the Kansk deposit.

Geologic structure of the deposit.

Seventy percent of the Kansk deposit consists of magmatic, mainly ultrabasic rocks, and 30 percent of sedimentary rocks (fig. 1).

The sedimentary rocks consist of Middle Devonian, Lower Carboniferous and early Jurassic formations. The most common are the Middle Devonian rocks, represented by conformable beds of limestone, various shales, sandstone, etc. The stratigraphic section of the Middle Devonian formations begins with a series of compact, glassy, silica-clay shale, about 100 meters thick. Higher, there is a series of rocks of variable thickness (60 to 170 m.), including light gray limestone and forming alternating layers with siliceous, jasper-like, sericitic,

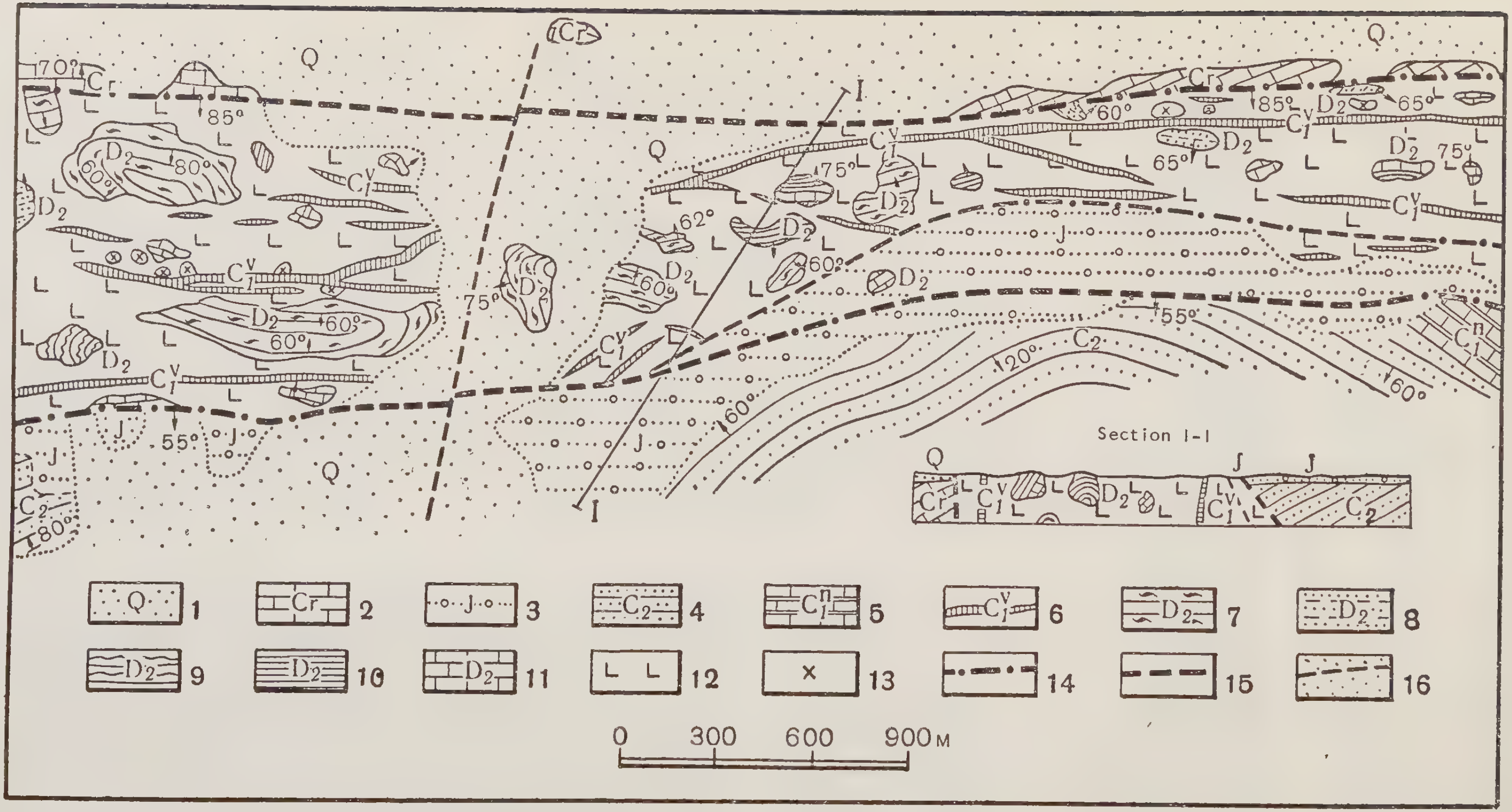

FIGURE 1. The Geologic Structure of the Kansk deposit (after I.P. Morozov, V.E. Dobryy and G.G. Kravchenko).

1 - Quaternary formations; 2 - limestone; 3 - conglomerate, sandstone, clay; 4 - sandstone, shale conglomerate; 5 - limestone, shale; 6 - limestone-serpentinite breccias; 7 - chlorite-sericite shale; 8 - clay and siltstone shale; 9 - jasper-like shale; 10 - siliceous shale; 11 - limestone; 12 - serpentinite; 13 - lamprophyre-like diorite; 14 - known tectonic displacements; 15 - suspected tectonic displacements; 16 - suspected tectonic displacements, covered by Quaternary formations.

clay-like, and other shales. These rocks are covered with a thick (370 meter) stratum of shales, including dark green chlorite-sericite, epidote-albite and other types. Higher in the section are limestone conglomerate, light gray limestone, sandstone and dolomite. The stratigraphic position of the rocks of this thin (10 to 80 m.) series, limited by tectonic contacts, is somewhat arbitrary. The youngest Middle Devonian rocks are green tuffaceous sandstones, clay-like feldspar-amphibole shale and limestone, which together form a series of variable thickness (110 to 150 m.). Serpentinite, found among the Middle Devonian rocks, is represented by xenoliths, the size of which varies from tens of centimeters to 1 kilometer and more. The finely granular, dark gray, Lower Carboniferous limestone (Visean stage), is distributed in linear zones among the serpentinite. In the southeastern part of the deposit there occur Jurassic clay, sandstone and conglomerate, lying on serpentinite.

Magmatic rocks are widely distributed and, according to data of Ya. S. Vis'nevskiy and others, are represented by a variety of types such as gabbro, syenite-aplite, albitophyre, quartz keratophyre, kersantite, gabbro-diabase, mandelstone, lamprophyre-like diorite, serpentinite-bearing peridotite, pyroxene, gabbro-pegmatite and other rocks. The appearance of the magmatic rocks took place during the period between Middle Devonian and Middle Carboniferous. The most common is serpentinite, which was formed by complete serpentinization of the youngest rocks -- peridotites. I.P. Morozov, A.D. Miklukho-Maklay and other workers separate the intrusion of peridotite into two groups of different ages, which were later completely serpentinized. The ultrabasic rocks of the first intrusion occupy a considerable part of the plain of the deposit. The serpentinite, formed at the expense of the periodotite of the second intrusion, occur as narrow, dike-like bodies in the limestone-serpentinite breccia zones. The rocks of the first intrusion survived among the younger serpentinite as fragments 0.1 to 15 meters in size, and occur in the structure of the limestone-serpentinite breccias.

Main tectonic features.

The region in question underwent a long tectonic deformation, resulting in the formation of the Kansk horst. Probably this structure first appeared in post-Middle Devonian time, when the border fractures of the horst appeared with a latitudinal direction and steep southern dip. The northern contact dips 85°; the southern, 55° to 85°. The border fractures were accompanied by a series of parallel, and connected, steep displacements, 1 to 2 meters and more thick. The movements along the fractures were often renewed prior to the appearance of dikes of various composition, and were accompanied by large-scale fragmentation of the sedimentary rocks. Later, hydrothermal solutions infiltrated the fractures. In the Alpine epoch the horst was elevated several hundred meters. Tectonic forces were also reflected in the formation of numerous folds, complicated by smaller folds, and in the pronounced plastic deformation of some rocks in the plain of the deposit.

The ore bodies of the Kansk deposit are found mainly in hard and brittle rocks; there is no considerable mineralization in the plastic rocks. Obviously, fractures were not formed in the plastic rocks, during the period of ore formation, and the hydrothermal solutions could not infiltrate them. In the brittle rocks numerous fractures appeared, and afforded channels of circulation for the ore solutions.

Conditions of formation of limestone-serpentinite breccias and limestone "veins."

Lower Carboniferous limestones containing Visean fauna are widely distributed around the Kansk deposit. Usually these rocks contain numerous fragments of serpentinite. The limestones containing fragments of serpentinite are called "limestone-serpentinite breccias." They extend among the serpentinite over 0.5 to 3 kilometers as linear zones in latitudinal, and occasionally northeastern and northwestern, direction. In the southern parts the dip of these zones is steep to vertical. Limestone-serpentinite breccias, according to I.P. Morozov, were encountered in mining at depths of up to 300 meters. The brecciated zones vary in thickness from 5 to 60 meters, averaging 20 to 30 meters. The limestone-serpentinite breccias within the zones are represented by fragments, distributed at random among the serpentinite. They are isometric, rounded, and occur about 5 to 10 meters from each other on the average. The sizes of these fragments vary from 0.2 to 5 meters.

In the zones studied there are intervals of up to several tens of meters, where the limestone is absent. Here, only angular fragments of serpentinite is observed. They are strongly cemented with crushed serpentinite, and only in a few cases are there observed small (1 to 10 centimeters) angular fragments of Visean limestone.

The composition of the limestone-serpen-

tinite breccias is fairly constant: the limestone contains fragments of serpentinite, which constitute about 95 to 98 percent of all the fragments. Fragments of pyroxenes, gabbropegmatites and limestones are rare; in addition, isolated fragments of shale are observed. The presence of veinlets of asbestos, magnetite and steatite in the fragments of serpentinite, but not in the limestone cement, indicates that the process of peridotite serpentinization was finished at the time of formation of the limestone-serpentinite breccias. The fragments of serpentinite and other rocks constitute 20 to 90 percent of the limestone-serpentinite breccias, but the usual amount is about 70 percent. Very often the fragments are suspended in the limestone, so that they appear to "float" in the limestone cement. The fragments are angular, and the sharp edges are seldom smoothed out. The fragments vary in size from a fraction of a millimeter to 0.5 meters, and occasionally to 3 meters. The average size is 10 to 15 centimeters.

In some places the fragments contain pieces of limestone-serpentinite breccias, and small (5 to 10 centimeters) angular pieces of very compact, crushed serpentinite, which in turn contain fragments of serpentinite of various sizes. In the limestone-serpentinite breccia zones there are often found characteristic "veinlets" of limestone, with "apophyses." The contacts of the "veinlets" are clearly visible; their thickness varies from fractions of a millimeter to 20 centimeters and the length from a few centimeters to 3 meters. The "veinlets" sometimes cut each other as well as the gabbro-pegmatite veins. Visean fauna was collected from various zones of the limestone-serpentinite breccias. The fossils are present in the limestone fragments, in the limestone cement and in the limestone "veinlets."

The presence of fossiliferous limestone associated with fragments of serpentinite, and the horizontal position of the limestone-serpentinite breccias led some researchers to the conclusion that these formations are of sedimentary origin, and that they should be considered as basal breccias. However, these theories are contradicted by a number of observed facts. The strike and the dip of the limestone-serpentinite breccia zones are not conformable with the Middle Devonian rocks, which appear as complex folds. There are no signs of gravitational differentiation of the fragments with depth in passing from one zone of limestone-serpentinite breccia to another. The angular shape of the fragments is characteristic. Obviously, in the case of accumulation of fragments due to wave action at the seashore, the fragments would be rounded and appear as pebbles. The theory of the sedimentary origin cannot explain the almost exclusively serpentinite composition of the fragments. In the entire region the ultrabasic rocks were found only in the Kansk horst, and 18 kilometers south of it. In the southern belt of ultrabasic rocks, the serpentinites take up 15 to 20 percent of the surface, while in the eastern part of the Kansk horst, about 30 percent, and in the Kansk deposit, 70 percent. Assuming that the most likely source of the fragments are the disintegrating rocks of the Kansk belt, it should be expected that not less than 30 percent of the fragments present in the breccias under discussion would be from the Middle Devonian sedimentary rocks. In fact, 95 to 98 percent of the fragments present in the breccias are serpentinite. The serpentinite content of the fragments also excludes the theory of accumulation of the fragments under continental conditions, with subsequent immersion, and later cementation by limestone. Furthermore, in this case, the sedimentary rocks should constitute not less than 30 percent of the fragments. The hypothesis of the sedimentary origin of the limestone-serpentinite breccias gives no satisfactory explanation of the observed distribution of fauna. The same fossil forms were collected in the angular fragments of limestone and in the limestone cementing the fragments. V.N. Krestovnikov identified the following forms: Paragoniatites newsoni (Smith). Metacanites cf. quinquelobus (Kittl.) and others. The Visean fauna were also determined in the in the limestone veinlets, cutting the limestone-serpentinite breccias. It is difficult to explain why fragments of serpentinite, including large fragments of up to 0.5 meters frequently occur in a suspended state. They appear to "float" in the limestone cement, without touching each other. Obviously, assuming the sedimentary origin of the fragments, they should be packed more tightly.

The linear distribution of the limestone-serpentinite breccias suggests the accumulation of limestone in the tectonic fracture zones, which appeared on the sea bottom. During later tectonic deformations the limestone was pressed into the fractures and between the limestone fragments. For such conditions it was necessary, according to simple calculations, to have at the sea bottom a layer of limestone 10 to 15 meters thick. The sediments should have had mobility similar to the mobility of water; otherwise, the cavities would be immediately filled with water after they appeared. However, the sedimentary material remains in the "fluid" state only in the uppermost part of the sedimentary horizon. Assuming the above hypothesis it could be expected that large fragments would "sink" in the mobile sediments. However, this has not been observed. The double and triple cutting of the limestone "veins" is also difficult to

explain. Furthermore, it cannot be explained how water was removed from the limestone sediment, particularly when it is assumed that marine conditions persisted during Visean and Namurian time and into the Middle Carboniferous period, as the limestone-serpentinite breccias were formed before the Middle Carboniferous period and possibly before the Namurian period.

Thus, the above hypotheses of the sedimentary origin of the limestone-serpentinite breccias can ot be considered as substantiated. At the same time, numerous observations lead to the conclusion that these breccias were formed during tectonic deformation, followed by plastic flow of the limestone into the fractures. Plastic flow is primarily indicated by the numerous traces, which are particularly frequent and plain in the limestone "veinlets" (fig. 2). This is also indicated by the orientation of the elongate fragments of pyroxene, actinolite, serpentinite fragments and other minerals, which are parallel to the contacts of the "veins." In some cases the oblong aggregates of actinolite and other radiating minerals are strongly crumpled, split and bent. The fauna is in places considerably deformed (fig. 3). In other places the fauna is well preserved, which could be explained by its somewhat greater strength as compared with the limestone cement. This is partly confirmed by well preserved Devonian fauna Gypidula ex gr. optata (Barrande) in a limestone "veinlet" cutting Visean limestone. It can be seen from fig. 4, that the veinlet containing the Devonian forms passes along the contact of a fragment containing abundant fauna, and farther on cuts fossiliferous limestone-serpentinite breccias. In the fauna taken from the limestone fragments and from the limestone cement V.N. Krestovnikov identified the same forms of the Visean age as Metacanites cf. quinquelobus (Kittl.). Obviously, in this case, the Devonian limestones "intersected" Carboniferous limestones only in the plastic phase, for the fauna shows no visible traces of deformation. In order to determine the degree of deformation of the fauna during the plastic flow process, an experiment was carried out, in which a cylindrical sample of the limestone con-

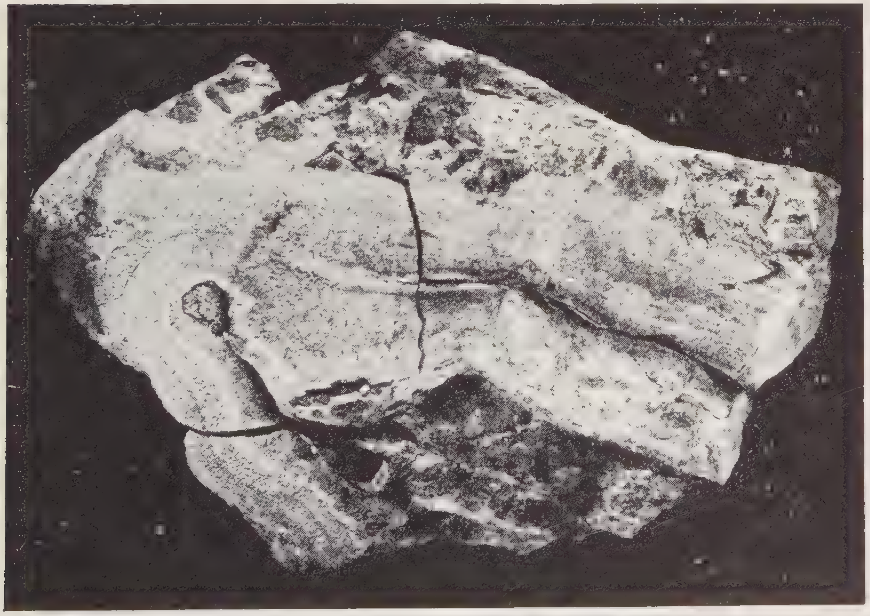

FIGURE 2. Traces of flow in a limestone "veinlet."

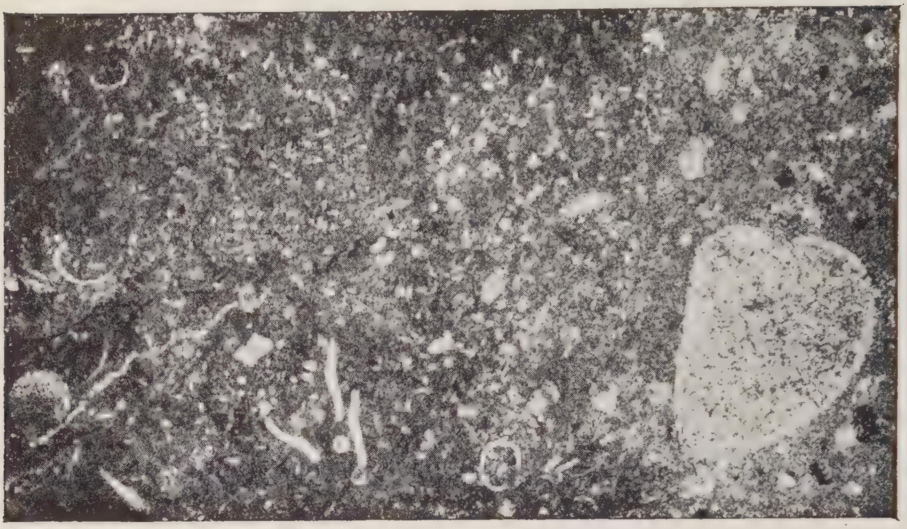

FIGURE 3. Deformed fossils. Enlargement x 37 with one Nicol.

taining microfauna was subjected to pressure from all sides. The original length of the sample was 22 millimeters and the original diameter, 14 millimeters; the final length was 17 millimeters and the maximum diameter was 19 millimeters. The sample, which was subjected to a pressure of 10,000 kg/cm. sq., assumed a barrel-like shape. In its most deformed central part the small fragments of serpentinite and other pieces of rock were oriented perpendicularly to the direction of the greatest force. At the same time the preserved fauna can be observed in this part of the sample (fig. 5). The extent of preservation of the fauna probably depends on its relative strength, on the intensity and duration of the tectonic deformation, and the degree of contamination of the limestones, etc. These conditions existed during the deformation of the fauna and also affected the

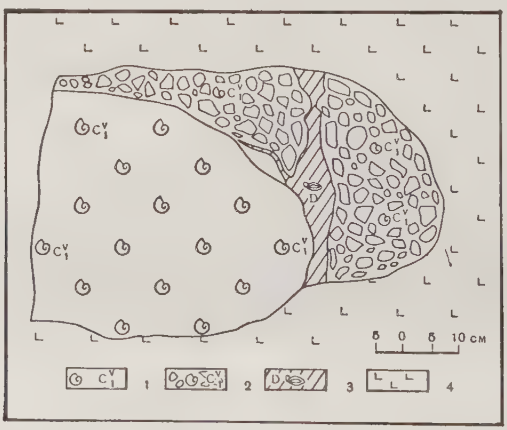

FIGURE 4. Correlation between Devonian and Carboniferous limestone.

1 - Fragment of limestone containing Visean fauna.
2 - Limestone containing fragments of serpentinite and Visean fauna.
3 - Limestone containing Devonian fauna.
4 - Serpentinite.

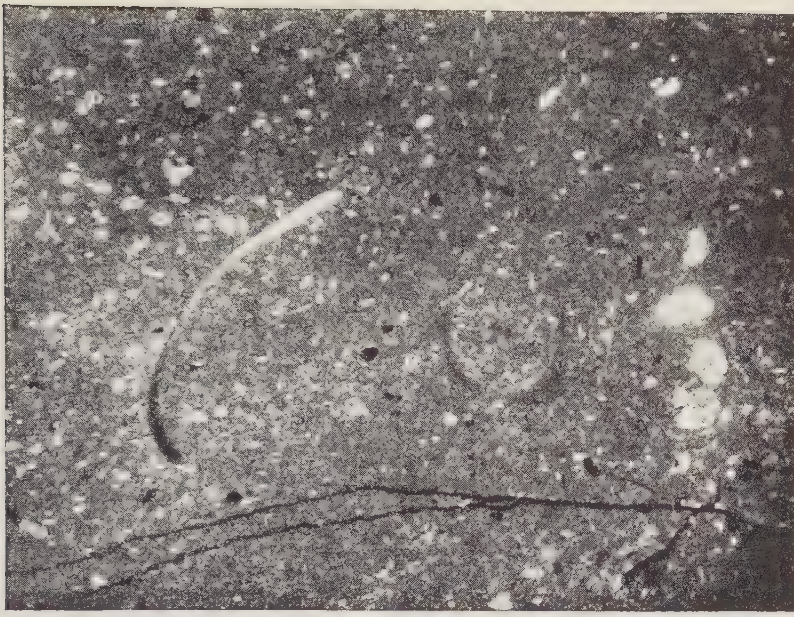

FIGURE 5. Fauna preserved in artificially deformed limestone. Enlargement x 16, parallel Nicols.

extent to which the shapes of the limestone fragments in the limestone-serpentinite breccias was preserved. In some cases the limestone fragments was angular, in others they are strongly deformed and have very elongate shapes, which are sometimes drop-like with constrictions. In the limestone cement there are also fragments of limestone which have completely lost their shape and gradually pass into the limestone cement.

During the deformation of the limestones which caused them to flow, they recrystallized at places in contact with the serpentenites. It is of interest that the borders of the recrystallized limestone can be distinguished only on one definite side, which is characteristic for all the fragments. The calcite grains in these borders also have the same orientation, thus emphasizing the direction of the deforming forces.

The results of the plastic flow of the limestone can be often observed in the separating of the serpentinite fragments. This leads to the formation of thin limestone "veinlets" cutting the serpentinite fragments from contact to contact and merging with the limestone cement (fig. 6). Obviously, as a result of the uneven pressure on various parts of the fragments, the latter gradually were fractured and recemented with plastic limestone. In some cases separation of fragments of limestone "veinlets" resulted in the appearance of thin, white calcite veinlets along the contacts. The termination of a limestone "veinlet" was observed in one of the relatively large fossils.

In order to prove that plastic deformation of the limestone (forming the veinlets) took place, microstructural analysis was carried out. Attempted determination of the orientation of the optical axes of calcite met with great difficulties, due to the considerable contamination of the limestone and to their finely granular state. The calcite grains in the limestone are usually of the order of one-hundredth or, more seldom, one-tenth of a millimeter. However, the measurements sufficiently identified B-tectonite with the b-axis in the plane of the limestone "veinlet" containing abundant microfauna (fig. 7).

Mutual intersecting limestone veinlets are often observed in zones of limestone-serpentinite breccias. Fig. 8 shows a "veinlet" of gray limestone. At the contacts are oblong

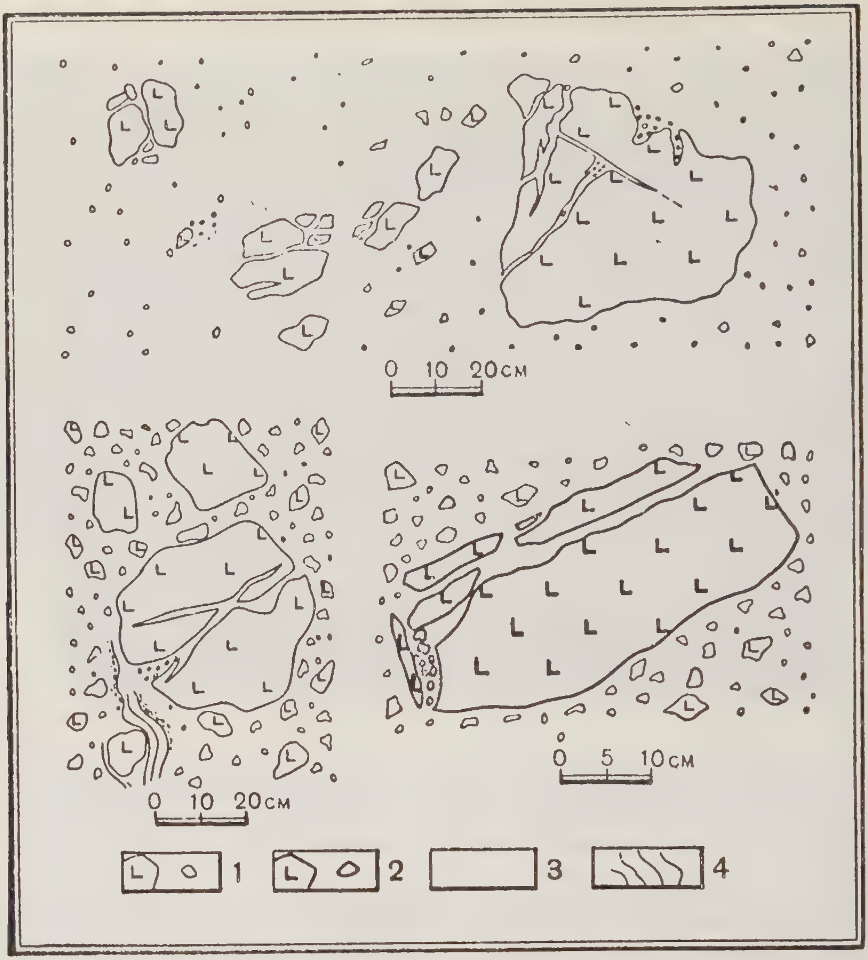

FIGURE 6. Serpentinite fragments spreading through limestone.

1 - Serpentinized peridotite; 2 - Serpentinized pyroxene; 3 - Limestone; 4 - Traces of flow.

accumulations of small serpentinite fragments (black), conformable with the contacts. A relatively large fragment of pyroxene, which was pressed into the material consisting of small fragments and oriented linearly can be seen in the upper left corner. It was deformed by pressure from one side. The intersecting vertical limestone "veinlet" contains small fragments of serpentinite, which are orientated parallel to the contacts of the "veinlet." Frequently in one fracture there are two or three parallel consecutive "veinlets" of limestone, the youngest of which is formed after the displacement and along the tectonic fractures of the earlier "veinlets."

Concluding the brief review of the structure of the limestone-serpentinite breccias, it should be emphasized that in addition to these breccia zones, there are breccias of latitudinal and nearly latitudinal direction, associated with zones having northeastern and northwestern directions and containing analogous breccias. This presents the basis of separation in the serpentinite of a system of main tectonic fractures with associated secondary fractures. These fractures are accompanied by limestone-serpentinite breccia.

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Consideration of the above, and other data, leads to the conclusion that the limestone-serpentinite breccias were formed during the process of plastic flow of limestones in tectonic fracture zones. The

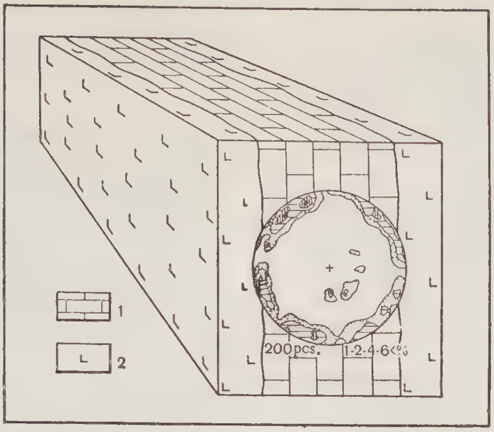

FIGURE 7. Orientation of the optical axes of calcite in a limestone "veinlet."

1 - Limestone with microfauna.
2 - Serpentinite.

following process of formation of these breccias appears to be the most probable: after serpentinization of the peridotite of the first intrusion, Visean limestone was deposited on the eroded surface of the serpentinite containing blocks of Middle Devonian rock. During the following deformations, there was once again movement along the previously formed tectonic dislocations. This caused the appearance of a series of fractures in the Visean limestone as well. Later, intense and prolonged pressure mainly affected the upper part of the horst. Since the horst is shaped like a wedge pointing upwards, the limestones, having acquired plasticity, were displaced along the tectonic fractures in serpentinite toward the zone of lower pressure, i.e., toward the lower part of the horst. Movement along the fractures caused the breaking and separating of the limestone. During further compression the limestone lumps in areas of greatest force again became plastic. The pressure was greatest in places where large masses of serpentinite were close together. The limestones, moving in a plastic state from such regions to the regions of lesser pressure, were distributed between the serpentinite fragments along the fractures in serpentinite and limestone which already had lost their plasticity. At the same time, other fragments of limestone, which were present in the narrow parts of the fractures, acquired plasticity.

Another possible theory on the formation of the limestone-serpentinite breccias assumes that the appearance of large lenticular blocks of Visean limestone in the fracture zones could be caused by numerous vertical movements. During the subsequent compression the limestone acquired plasticity and was displaced upwards along the fractures, together with fragments of serpentinite.

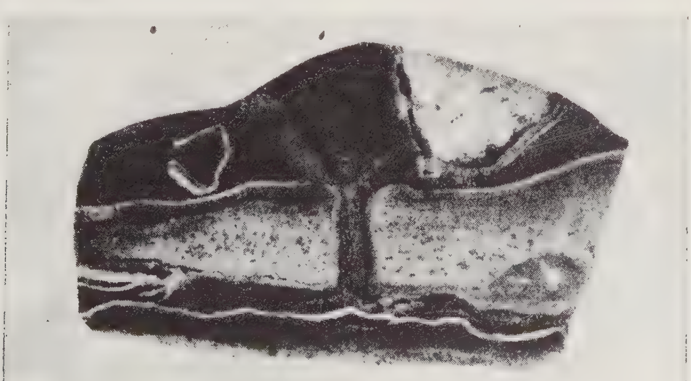

FIGURE 8. Intersection of limestone "veinlets."

Natural size.

After the formation of the limestone-serpentinite breccias, there appeared in the brecciated zones the second intrusion of the ultrabasic rocks such as peridotite dikes. The dikes also contained fragments of limestone-serpentinite breccias which appear to have been fused.

Thus, in the area of the Kansk deposit, results of the plastic deformation are common. While plastic deformation of rocks is apparently a very common phenomenon, it is difficult to identify due to lack of clear criteria for such phenomena.

Discussing the problem of plastic deformation of rocks, G.D. Azhgirey [1] indicated that even "granite under certain, frequently encountered conditions, are deformed like plastic bodies." As an example he gave the plastic deformation of granite of the central Caucasus [2]. A case of plastic flow of argillites in a tectonic fracture zone was also considered by F.I. Vol'fson [3]. The last example illustrates the complexity of identification of the plastic flow phenomenon. Argillites, forced upward along faults for hundreds of meters, for many years were considered as tectonic clay, formed during the breaking and crushing of rocks. Analogous examples of plastic flow of rocks in fracture zones in the Broken Hill deposit was given by E. Andrews [10]. Numerous occurrences of clay and carbonate "dikes" are described in the review by R.G. Garetskiy [4] and in a paper by R. Shrock [9]. The inclusion of rock fragments in the movement of plastic rocks was reported in the papers of A.V. Pinzher [7] and A.A. Ivanov [5]. The latter also cites examples of the formation of vein-like salt deposits, pressed in clays. "Veinlets" of various sedimentary rocks in anhydrites were observed by N.M. Strakhov [8]. "Veinlets" of limestone in crystalline shale were reported by I.G. Kuznetsov [6].

CONCLUSIONS

The problem of the origin of the limestone-serpentinite breccia is important for the understanding of the entire geologic history of the Kansk deposit, and for its elevation. Mapping of the limestone-serpentinite breccia zones, and study of the structural details, disprove the theory of the sedimentary origin of these formations, and leads to the conclusion that the breccias were formed during the process of plastic flow of limestones in zones of tectonic fractures.

Plastic deformation of rocks is probably very common in many regions, and the identification of this process, while difficult, can be of real importance, both in the solution of geological problems, and in the solution of problems of ore localization.

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Institute of Geology of Ore Deposits, Petrography, Mineralogy and Geochemistry, Academy of Sciences, U.S.S.R., Moscow.

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ON THE RELIEF OF LIMESTONE FOUNDATION IN THE SUB-MOSCOW BASIN

by

I. P. Lomashov

1. Introduction

The term "limestone base" in the Moscow Basin, is used for the complex of predominantly carbonate rocks, underlying the sandstone and clay formations of the Stalingorsk coal bed. These rocks are referred to the Likhvin and Chernyshin sub-stages of the Lower Carboniferous system and to Dankov-Lebedyan stages of the Upper Devonian system.

Most geologists, studying the Moscow Basin, believe that the transition from the base to the rocks covering it is sharp, and is erosional in character.[1]

The surface of the limestone base is not smooth. In addition to the general dip toward the center of the Moscow syncline, equal to 1.5 to 2 m./km., it is characterized by the presence of locally significant irregularities. These irregularities have been described commonly in the literature.

From his studies of the structure of the southern and southwestern parts of the Moscow syneclise, V.A. Zhukov [3] concluded that the surface of the limestone base in general dips in the direction of Moscow, but at different angles. In some cases the dips average 0.1 to 0.3 m/km., in others 3.7 to 4.2 m/km. The zone of the steepest dips west of Ryazan' is divided into three subzones. The outside one passes through Kaluga, the middle one through Serpukhov, and the inside one through Moscow. Between these subzones the surface of the base is characterized by gentle dips. The alternation of the zones of various dips forms a terrace in the shape of an arc, which extends over all the syneclise parallel to its edge. According to V.A. Zhukov, the formation of the terrace, which took place before the accumulation of the Stalinogorsk bed, is connected with the development of the syneclise itself, and probably was caused by fracturing in the crystalline base.

The terraces discovered by V.A. Zhukov are tectonic elements of the second order with respect to the Moscow syneclise, and are accompanied by smaller dislocations, structures of the third and fourth order. According to E.A. Kudinov [4], most of these dislocations are situated in the area between the Moscow syneclise and Voronezh anticlise, i.e., in the territory situated near the town of Tula. M.I. Grayzer [2] developed the ideas of V.A. Zhukov and discovered in this area, in the uppermost part of the Malevsk bed, the Tula-Kaluga zone of elevations, extending over more than 250 km., from the Skopin to Kaluga, through Stalinogorsk and Tula, and limited in the south by the Gorlovka-Lyutorich-Lomintsev depression. M.I. Grayzer believes that the relief of the limestone base is due to vertical movements of individual blocks in the crystalline basement.

For a number of years, the author of the present article studied the material provided by the exploratory drilling for coal in the central part of the southern flank of the Moscow basin. The territory studied, an area of about 5,000 km. sq., comprises the administrative regions of Tula and Moscow. The results of the author's studies on the limestone base are given below:

2. Relief of the Base.

The surface of the limestone base in the territory studied is inclined in the northeast.

Editor's note: The term "limestone base" as used in this paper, refers to a group of sedimentary layers forming the bedrock foundation in the Moscow basin.

[1] There are other theories; for example, L.M. Birina [1] admitting the erosional character of limestone of the Upinsk bed, believes that the limestone of the Chernyshin sub-stage, towards the east, pass gradationally into the sandstone and clay deposits of the Stalinogorsk bed.

In its southern part, the maximum relief reaches 210 meters,[2] decreasing towards the northeast to 80 meters. Maximum relief over the distance of 60 to 70 km. is, therefore, 130 meters. The dip of the surface is thus equal to 2 m./km., i.e., it is approximately the same as the general dip of the southern limb of the Moscow syneclise. Regarding the general inclination of the surface of the base there are numerous irregularities having a relief of several tens of meters over short distances. The hypsometric map (fig. 1) shows four principal elements of relief: Southern elevation, Lomintsev flexure, Tula-Kaluga elevation and Mikhaylov flexure. Their area is very large and extends beyond the limits of the studied territory.

1. The Southern elevation is situated in the southern part of the area studied (fig. 1). The absolute relief is 180 meters, the maximum elevation being about 210 meters. It is bisected in the meridional direction by the Upa River, which causes a decrease in the relief of the base to 160 meters. The axis of the elevation is situated somewhere in the south, beyond the area of coal-bearing formations. The northern limit of the elevation, within the limits of the territory studied, isohypse 160 meters, trends northwest for about 70 km. Its southeastern and northwestern limits have a minimum elevation of 160 meters. Maximum relative relief in the neighboring regions is about 90 meters. The dip of the surface toward the north reaches 15 to 20 m./km., and averages about 10 m./km.

2. The Lomintsev flexure extends from the Southern elevation in a northwesterly direction (fig. 1) as a valley about 90 km. long and 3 to 5 km. wide, with a mean elevation of 150 meters, decreasing in places to 120 meters. Its middle part is the highest, but does not exceed 160 meters. The Lomintsev flexure becomes considerably wider at its northwestern end and sinks to 110 meters elevation.

3. The Tula-Kaluga elevation is the part of the larger zone of Tula-Kaluga elevations, discovered by M.I. Grayzer [2]. It trends across the studied territory in a northwesterly direction, north of the Lomintsev flexure. Its relief averages 170-180 meters, the maximum relief being 195 meters. The length of the elevation within the territory studied is about 70 km. and the width in places is 25 km. Southwest of it there is a sharp decline to 130-140 meters. Toward the east there is a gradual decrease of relief to 160 meters. In its central part, the elevation branches into several small individual elements, due to recent erosional action of the Upa River and its tributaries, the Sezha, Shat and Shivoron. Maximum relative relief in this area, in relation to the valley situated in the south, is about 80 meters, and in relation to the valley situated in the north, about 110 meters. The dip of the surface of the base toward the south reaches 15 to 20 m./km., and averages 10 m./km. The dip toward the north averages 4 m./km., the maximum being 8 to 10 m./km.

4. The Mikhaylov flexure is situated north of the Tula-Kaluga elevation. Its outline is arbitrary because the greater part of it is outside the limits of the territory studied (in the region of Mikhaylov), I did not investigate it in detail. The elevation of the surface of the flexure within the limits of the map area (fig. 1) is 80-140 meters.

In addition to the above principal features, which are complicated by erosional valleys, there are isolated oval and round cavities on the surface of the limestone base. Their origin is associated with karst processes, which are very strongly developed in the Moscow basin; the cavities are not large. Consequently, although they affect the micro relief of the limestone base, they do not play any noticeable part in the shaping of its major features.

3. Stratification of the base.

The stratification of the limestone base in the Moscow basin is determined from the study of the uneroded surface of the Malevsk bed, where the strata are relatively easily identified. It is seen from the hypsometric map of the surface of the Malevsk bed (fig. 2) that the limestone layers of the base are not flat-lying. In the southern part of the region their elevation is 179 meters, and in the northeast it decreases to 70 meters. The extreme elevation is 110 meters, and the dip of the layers averages about 1.7 m./km. In addition to the general inclination towards the northeast, smaller flexures are present. They correspond to the principal relief features, which were described above: Southern elevation, Lomintsev flexure, Tula-Kaluga elevation and Mikhailovsk flexure. In the region of the Southern elevation the maximum elevation of the surface of the Malevsk bed is 179 meters. Farther to the north, in the Lomintsev flexure, the maximum elevation averages 140 meters. The dip of the beds here averages 4 m./km., with a maximum of 6.5 m./km. In the zone of the Tula-Kaluga elevation the maximum elevation of the layers increases again to 175 meters, and to the north decreases to 70 meters. The

[2] All subsurface elevation figures are measured from sea level.

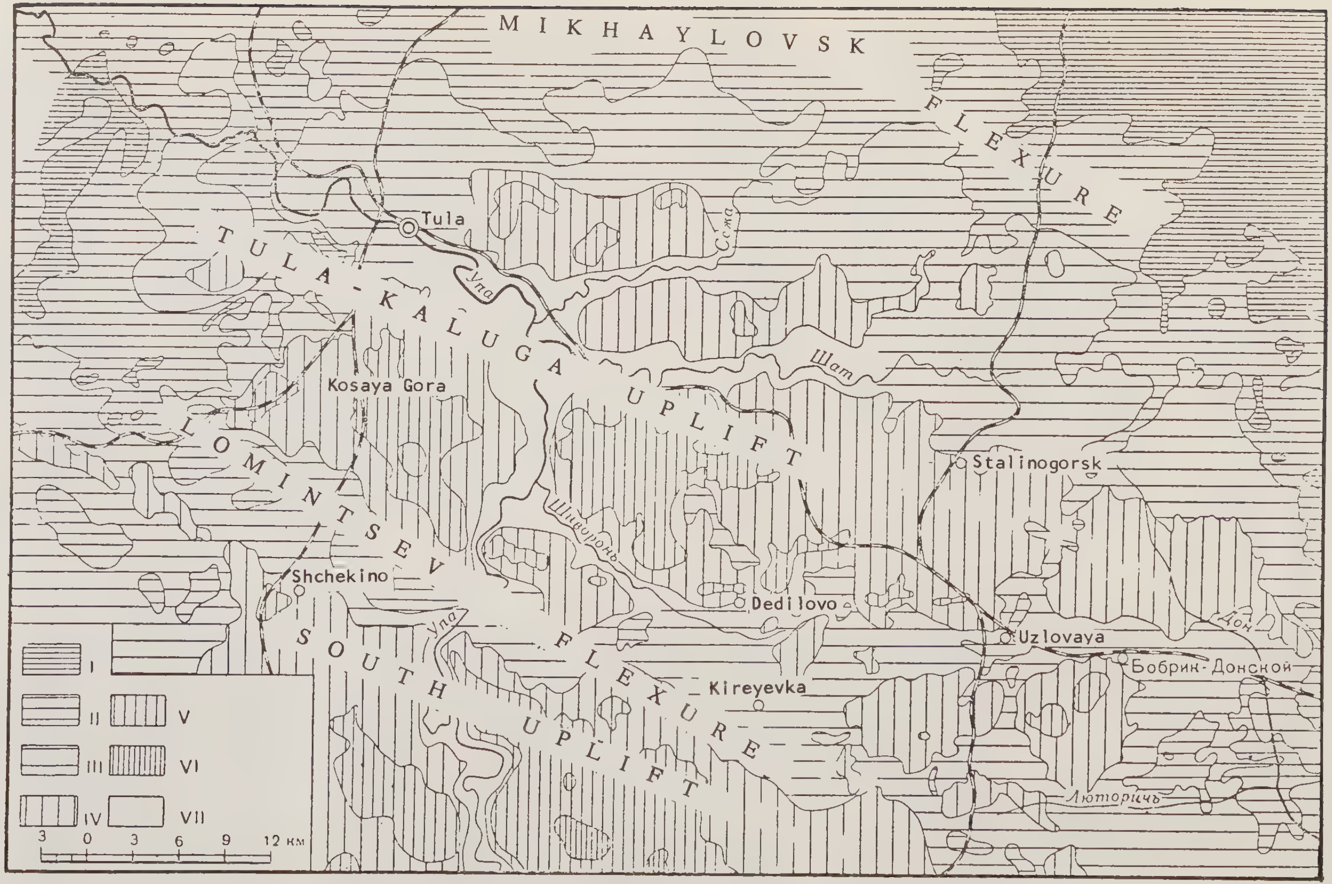

FIGURE 1. Map of the contemporary relief of the limestone base (Central part of the southern flank of the Moscow Basin).

Elevation of the limestone base: I - 80 to 125 meters; II - 120 to 140 meters; III - 140 to 160 meters; IV - 160 to 180 meters; V - 180 to 200 meters; VI - more than 200 meters; VII - parts of the base eroded by contemporary rivers.

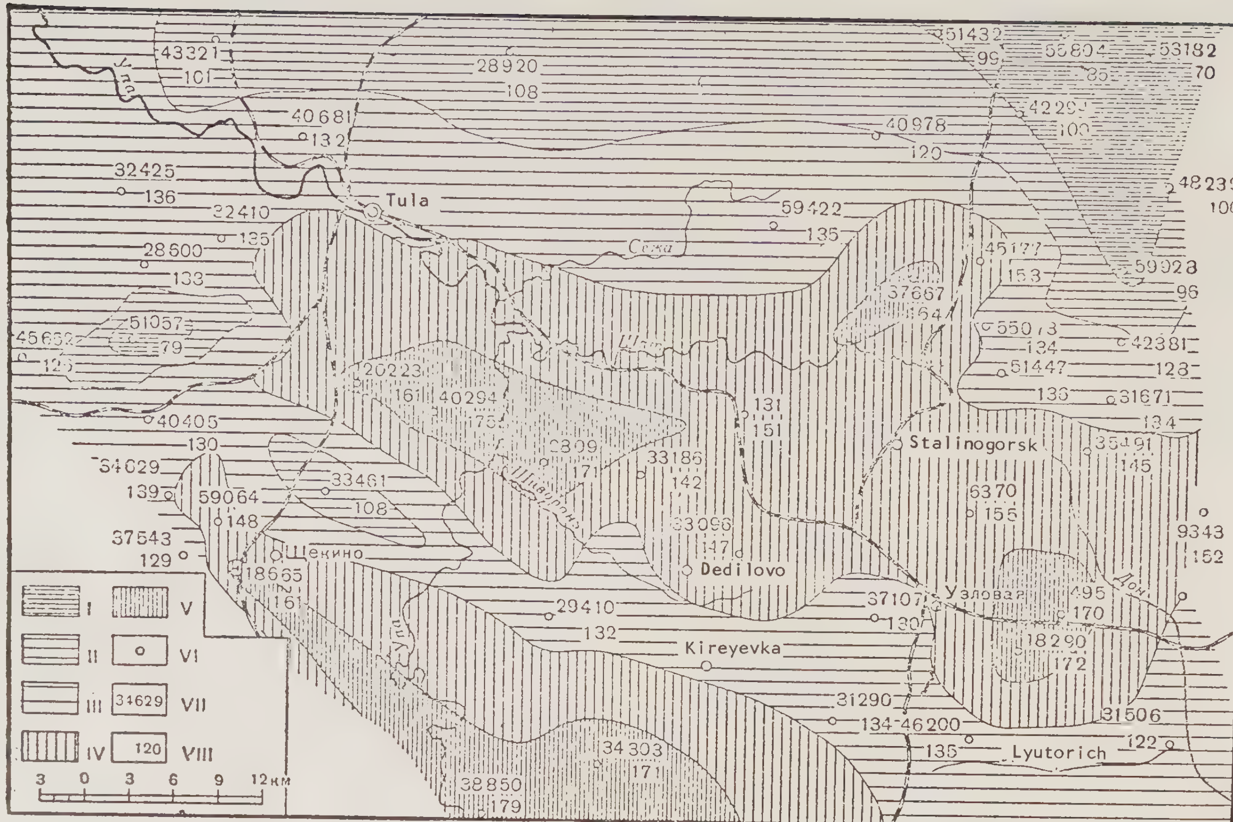

FIGURE 2. Scheme of the hypsometry of the top of the Malevsk stratum (Central part of the southern Moscow Basin).

Elevations of the top of the Malevsk stratum: I - 70 to 100 meters; II - 100 to 120 meters; III - 120 to 140 meters; IV - 140 to 160 meters; V - 160 to 170 meters; VI - borehole; VII - number of borehole; VIII - absolute elevation of the top of the Malevsk stratum.

dip of the surface of the Malevsk bed, south of the Tula-Kaluga elevation, averages 4 m./km. It should be mentioned that the folds in the limestone base, which were discovered by drilling, were confirmed by the data from electro-prospecting work.

4. Geologic structure of the base.

The surface of the base almost everywhere is represented by the formations of the Upinsk bed of the Likhvinsk sub-stage of the Lower Carboniferous system (fig. 3). Only in

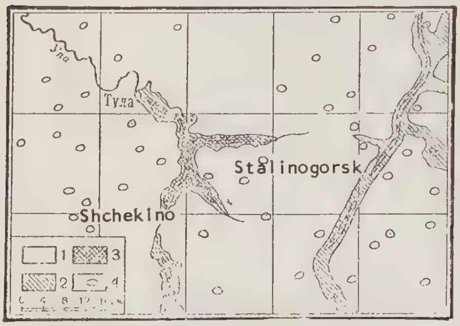

FIGURE 3. Schematic geologic map of the surface of the limestone base.

Formations appearing on the surface of the base: I - Upinsk bed; II - Malevsk bed; III - Upper Devonian; IV - boreholes which reached the Malevsk stratum.

isolated places do older rocks of the Malevsk bed and Devonian rocks reach the surface. They reach the surface of the base in narrow and elongate inliers, representing erosional valleys of old and contemporary rivers. Only two such inliers were discovered (fig. 3): one is 1 to 2 km. wide and more than 60 km. long, across the eastern part of the region from southwest to northeast. Its formation is due to the erosional action of the old rivers. The other, which is also 1 to 2 km. wide, is situated along the Upa River, above Tula, and is joined to two small inliers, situated along the Shat and Shivoron tributaries of the Upa River: The small inliers extend over 10 to 15 km. from the mouth of each tributary. All the outlets of the second inlier are due to the erosional action of the contemporary Upa River and its two tributaries.

In addition to those discussed above, formations older than the Upinsk bed reach the surface of the base, but are not shown on Figure 3 because of their small size.

5. Pre-Carboniferous relief of the limestone base.

The study of the relief of the limestone base is of considerable importance, particularly for the understanding of the conditions of accumulation of coal-bearing formations. Many investigators realized long ago the possibility that the change in relief is a result of tectonic movements, which took place after deposition of the Stalinogorsk bed. These movements are now accepted as a proved fact. The problem now consists of finding an explanation for the changes which took place in the principal elements of relief of the base during their development, and particularly after the formation of the coal beds.

As I indicated earlier [6], for the reconstruction of the pre-Carboniferous relief, the coal beds can be arbitrarily considered as a horizontal surface. The thickness from the base of the coal beds to the top of the limestone base can be measured. The greatest thickness would correspond to the lowest elevation of the pre-Carboniferous relief. Obviously, by this method of reconstruction it is not possible to represent all the details of the relief, because before the accumulation of coal the surface was not ideally smooth; it is possible to explain the irregularities which appeared after deposition of the Stalinogorsk bed, and consequently to reconstruct the principal relief features existing before the formation of coal. The possible error consists only in the smoothing out of the irregularities which existed. The general distribution of the negative and positive pre-Carboniferous relief features is correctly reconstructed by this method.

The reconstruction of the pre-Carboniferous relief was carried out in places where the main layer of coal exists. The absence of this layer in some places is due to two main causes: non-deposition and erosion. In the latter case, the pre-Carboniferous relief is reconstructed arbitrarily by the interpolation of available data. Where the coal layers were eroded, interpolation of the pre-Carboniferous relief can be effected with little error by using a clay bed which is found in the middle part of the main coal-clay complex.

In order to reconstruct the pre-Carboniferous relief of the limestone base by the above method, a map was prepared (fig. 4). A map of the presumed elevations of the top of the Malevsk bed was constructed to show the stratigraphic conditions prior to coal formation (fig. 5). The latter map was constructed by the same method as the map showing pre-Carboniferous relief, except that the distance was not measured from the base of the main coal layer to the surface of the limestone base, but rather to the Malevsk beds. It is seen in Fig. 4 that the surface of the limestone base in pre-

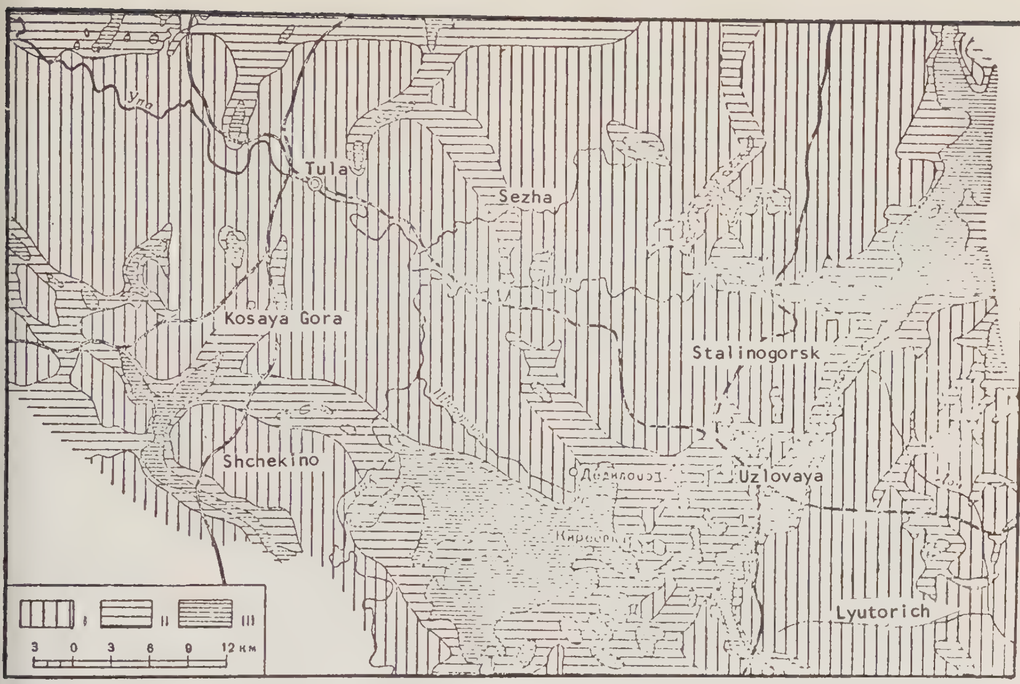

FIGURE 4. Map of the pre-Carboniferous relief of the limestone base (Central part of the southern flank of the Moscow Basin).

Distance from the base of the coal to the surface of the limestone base: I - 0 to 10 meters; II - 10 to 20 meters; III - more than 20 meters.

Carboniferous time was not smooth. Even at that time the four principal elements could be observed, as shown on the map of the contemporary relief. However, at that time they were not very pronounced.

The Southern elevation, about 50 km. long, trends northwest. The difference of elevations with respect to the surrounding lowlands does not exceed 30 to 35 meters. The flexing of the strata on the surface of the Malevsk bed is insignificant; the dip averages only 1 m/km, and the differences of the elevation of strata on the Malevsk bed are about 10 m.

The Lomintsev flexure extends to the northwest. Its length is about 60 km, the width increases in the northwest from 2 to km, to 20 kilometers in the southeast.

The Tula-Kaluga elevation is characterized by the least thickness from the coal layer to the limestone base (less than 10 meters). In pre-Carboniferous time this elevation was more than 80 km long, and traversed all the described territory in a northwesterly direction in the form of a wide belt, passing approximately through the center of the area. The area of this belt covers not less than one half of the area, and even more in the eastern part. The relief with respect to the surrounding lowlands reaches 6 meters. The flexures on the surface of the Malevsk bed have an amplitude of 19 meters. The dip of the strata to the north and south is no more than 2 m/km, and on the average does not exceed 1.5 m/km.

The Mikhaylovsk flexure was hardly present in pre-Carboniferous time. It was situated in the extreme northern part of the area studied.

In addition to the four folds described, there were other relief features on the surface of the base in pre-Carboniferous time which were not the reflection of structure. They are very pronounced, narrow cavities in the limestone base, obviously the erosional valleys of the old rivers. This is indicated not only by their configuration, but also by the composition of rocks with which they are filled. Two such valleys are shown on Fig. 4, the Eastern and Western. The Eastern valley passes through all the territory described in a northeasterly direction, east of Stalinogorsk, as a long (more than

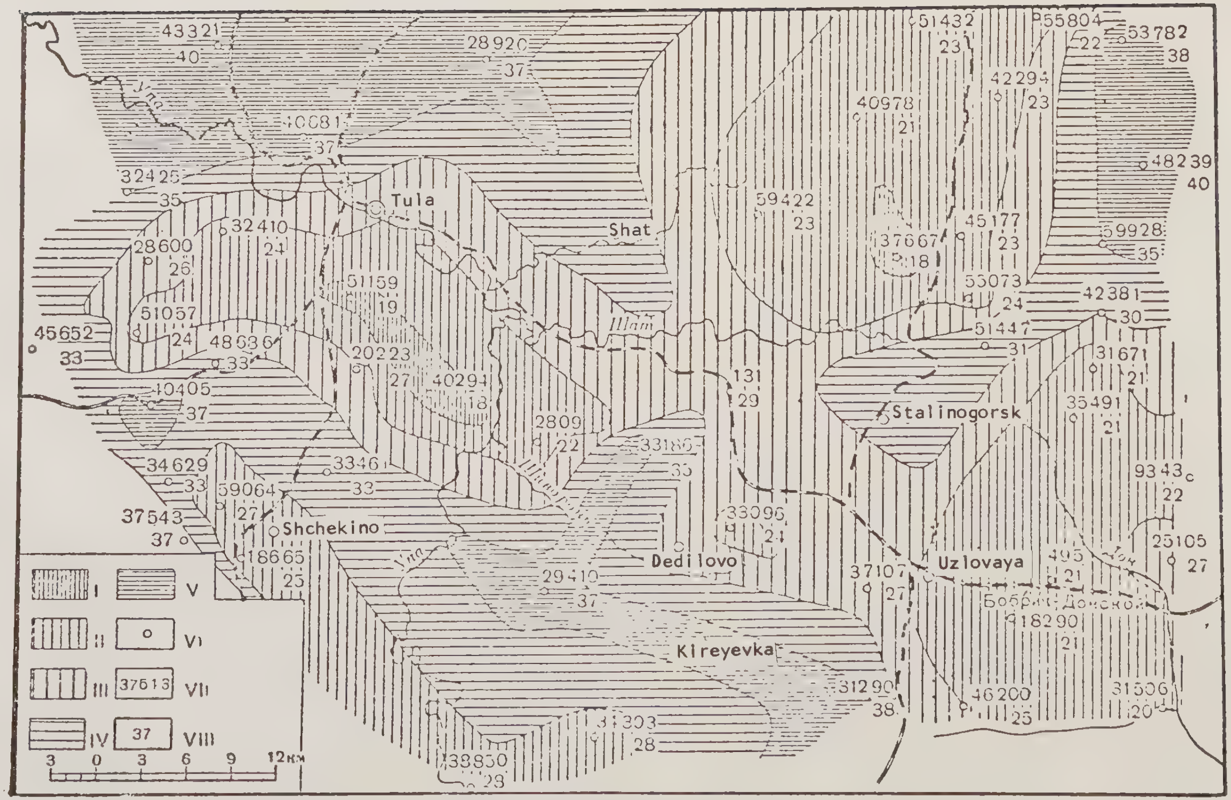

FIGURE 5. Hypsometry of the top of the Malevsk stratum in pre-Carboniferous time (Central part of the southern flank of the Moscow Basin).

Distance from the base of the coal to the top of the Malevsk bed: I - 18 to 29 meters; II - 20 to 25 meters; III - 25 to 30 meters; IV - 30 to 35 meters; V - 35 to 40 meters; VI - borehole; VII - number of borehole; VIII - distance from the base of the coal to the top of Malevsk (in the boreholes).

60 km.) belt, 1 to 2 km. wide. The valley widens to 4 to 5 km. in the northeast, which indicates that the river was flowing in that direction. The depth of the valley reaches 60 meters, averaging more than 30 meters. By erosion of the upper formations, it uncovered the Malevsk bed and Devonian formations. North of Stalinogorsk, the eastern valley of the old river is joined by a small tributary, 18 km. long, and 1 to 2 km. wide, averaging 30 m. deep, but in places up to 45 meters. In the contemporary relief of the limestone base, the Eastern valley is not very pronounced, but its general features were preserved up to the present time (fig. 1), particularly in the northeastern part of the river. Where the Eastern valley crosses the Tula-Kaluga elevation, it is barely noticeable. The elevation of the Tula-Kaluga area, which took place after the disposition of the Stalinogorsk bed brought about erosional action, as a result of which the coal-bearing deposits completely destroyed, and the old irregularities of the relief were evened out in parts of the Eastern valley.

The Western valley begins at the Southern elevation and trends northwesterly. Southwest of Shchekin, it joins the Lomintsev flexure. It is about 30 km. long, 1 to 2 km. wide, averaging 15 to 20 meters deep, but in places up to 35 meters deep. It is joined by two small valleys. In the contemporary relief of the base, the traces of the Western valley did not survive everywhere.

It should be mentioned that because erosion has removed the coal layer, and in places all of the Stalinogorsk beds, some of the valleys cannot be traced over their entire length. In such cases, the direction of these valleys is shown on the map arbitrarily (broken line). This probably does not involve a large error, because the traces of the old cavities commonly survived in the contemporary relief of the base, although they are commonly somewhat deformed.

In addition to the above-mentioned large valleys, several cavities were marked on the map ranging between 10 to 15 km. long, 1 to 2 km. wide and about 15 meters deep. They all begin in the Tula-Kaluga elevation and extend either to the north or south, towards the Mikhaylov and Lomintsev flexures, respectively.

6. The origin of the relief of the base.

The new data obtained from drilling suggest the following history of formation of the relief of the limestone base. During the uplifts which took place in post-Upinsk time, the beds of the limestone base underwent slight folding. At that time, and perhaps somewhat earlier, the following principal tectonic features originated: The Southern and Tula-Kaluga elevations and the Lomintsev and Mikhaylov flexures, which constituted the irregularities of the relief with a maximum difference of altitudes of only 20 meters. The tectonic origin of these relief features is confirmed not only by the flexing of the strata of the Malevsk bed, which extends over several tens of kilometers, but also by the parallel position of the flexures.

During later uplift of the region, which took place during the long continental interval, the erosional action of rivers took place. Although the original dip of the beds was insignificant, it was sufficient for the determination of stream flow. A complex system of river valleys was formed, the character of which was not identical for all of them. Some of them flowed down large tectonic flexures and had wide and shallow (20 to 30 meter) valleys, with repeatedly changing courses; others flowed down the slopes of tectonic elevations or even intersected them. In the latter case narrow, deep (up to 60 meters) valleys were formed. Here, the Eastern and the Western valleys and their small tributaries belong. The pre-Carboniferous relief was formed this way, and had a maximum relief of 60 meters.

What changes in this relief occurred later, after the deposition of the main coal layer? It is known that the development of the territory studied was very complex, and was subjected to numerous positive and negative movements. During the intervals between the tectonic movements the relief of the limestone base was no doubt changed in some way. In order to determine these changes in the individual stages the method described in literature [5] could be used, which consists of rectification of surfaces. By means of this method it is easy to reconstruct the relief at any time.

Unfortunately, in the territory studied the limestones of the Oka sub-stage are the only ones which make it possible to determine the changes of relief which occurred during the pre-Tula elevation. However, these limestones are not found everywhere, and, therefore, even the incomplete history of the development of the relief cannot be studied in the entire area, but only in parts of it. A suitable place for this study is the region situated north of Shchekin. This region is relatively large (more than 400 km. sq.) and is convenient for the study, because the limestones of the Oka sub-stage are well developed there, and it includes parts of some of the tectonic relief features such as the Southern and Tula-Kaluga eleva-

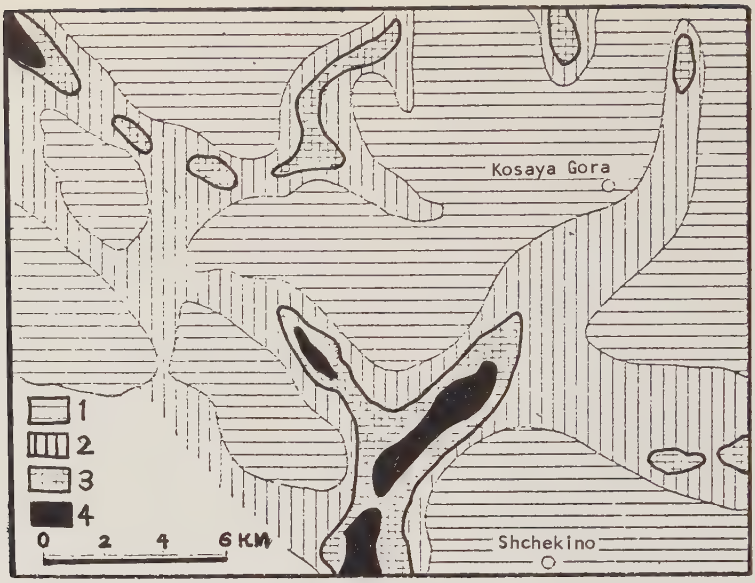

FIGURE 6. Schematic map of the pre-Carboniferous relief of the limestone base.

Distances from the base of the coal to the limestone base, reflecting its relief: 1 - less than 10 m.; 2 - 10 to 20 meters; 3 - 20 to 30 meters; 4 - more than 30 meters.

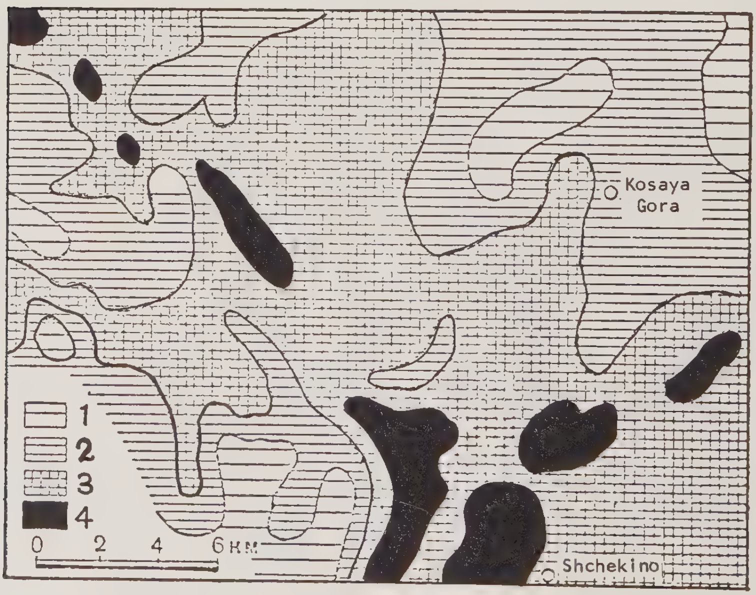

FIGURE 7. Schematic map of the relief of the limestone base before the formation of the limestones of the Oka sub-stage.

Distances from the base of the Oka sub-stage to the limestones of the base, reflecting the relief of the latter: 1 - less than 30 meters; 2 - 30 to 50 meters; 3 - 50 to 70 meters; 4 - more than 70 meters.

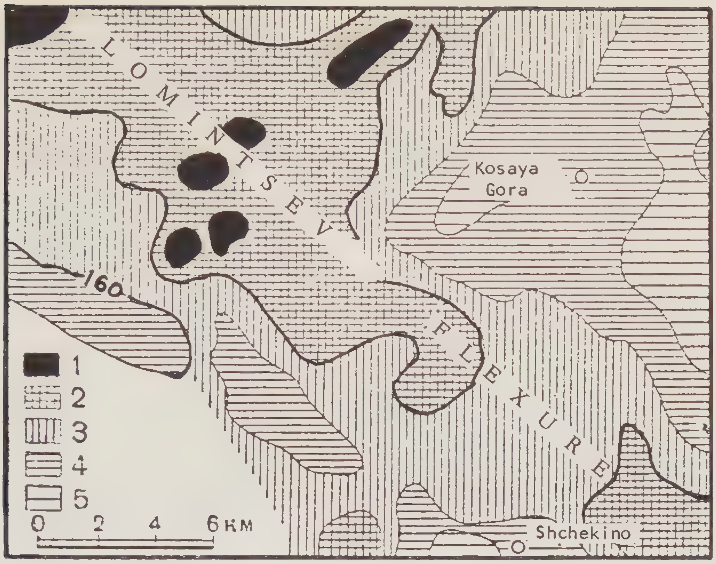

FIGURE 8. Schematic map of the contemporary relief of the limestone base.

Elevation of the base: 1 - less than 120 meters; 2 - 120 to 140 meters; 3 - 140 to 160 meters; 4 - 160 to 180 meters; 5 - more than 180 meters.

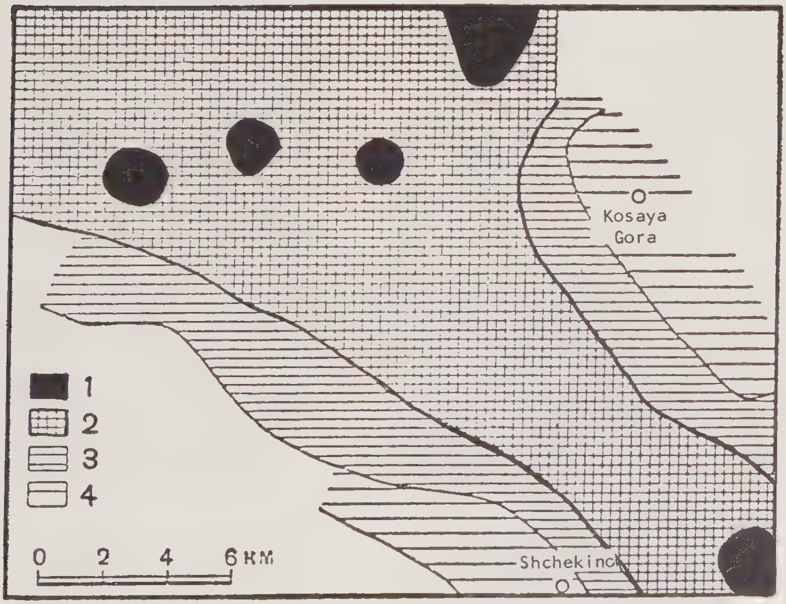

FIGURE 9. Schematic hypsometric map of the limestones of the base of the Oka sub-stage.

Elevation of the bottom of the limestones: 1 - 180 meters; 2 - 180 to 200 meters; 3 - 200 to 220 meters; 4 - more than 220 meters.

tions, and is situated on the Lomintsev flexure.

The pre-Carboniferous relief in this area was not smooth (fig. 6). It contained the valley system of the western Paleo River and its tributaries. The Lomintsev flexure was not well marked. Maximum relief was 30 to 40 meters.

The relief of the base before the formation of the limestones of Oka sub-stage (reconstructed according to the position of the bottom surface of these limestones) differed from the pre-Carboniferous relief by being more complex. Here, the trend of the Lomintsev flexure is well marked. Maximum relief was about 50 meters (fig. 7). Consequently, during the Tula erosion period some movements took place which complicated the relief by increasing the difference of elevations by 10 to 20 m. as compared with the pre-Carboniferous relief.

It is difficult to determine what changes took place in the later part of the continental intervals. It is only known that during the time since the formation of the limestones of the Oka sub-stage, the limestone base was flexed by 40 to 50 meters, and the Lomintsev flexure became more marked (fig. 8). It is interesting that the limestones of the Oka sub-stage was flexed to the same degree (40 to 50 m.) (fig. 9).

Thus, it is seen from the example of this territory, that the changes of relief of the limestone base, which took place since its formation until the present time, caused its further complication. This is reflected in the more pronounced appearance of the principal tectonic forms, which originated in pre-Carboniferous time.

The comparison of the map of the pre-Carboniferous relief (fig. 4) with the map of the contemporary relief of the limestone base (fig. 1) makes it possible to extend the above conclusion to all the territory studied, i.e., it indicates that the principal structural forms complicated by erosion -- the Southern and the Tula-Kaluga elevations and the Lomintsev and Mikhaylov flexures, continued to develop during all the geologic history, after their formation in pre-Carboniferous time. They also preserve their general character. Judging from the above example it can be assumed that the main movements which changed the relief took place after the formation of the Oka limestones.

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BRIEF COMMUNICATIONS

ON CENOMANIAN DEPOSITIONS OF THE CRIMEAN MOUNTAINS

by

N. I. Maslakova and D. P. Naydin

Cenomanian deposits of the Crimean ountains are represented by various clayey ıd sandy marls which contain layers of mestone in their upper part. The change of ıe lithologic composition and thickness of e Cenomanian deposits in the Crimean ountains is shown in Fig. 1.

The age of these deposits is determined the presence of characteristic Cenomanian ssils: Inoceramus, ammonites, belemnites ıd foraminifera. In all the sequences udied Inoceramus crippsi Mant. and In. alprum Boehm (In. etheridgei Woods) are dely distributed.

The most common ammonites are Puzosia bplanulata (Schlut.) and Acantroceras manlli (Sow.), which are found mainly in the iddle part of the Cenomanian sequence of e Crimea. These forms are found in the wer and upper part of the sequence also. ıe remains of Schloenbachia varians (Sow.) e found less frequently. They occur roughout the Cenomanian sequence of the khchisaray region. The above mentioned ımonites are typical cephalopod of the nomanian formations of Europe, Asia and rica.

Scaphites aequalis (Sow.) and Gaudryceras cya (Forb.) have been identified in upper nomanian horizons of the Bakhchisarsi and logorsk regions. Scaphites aequalis (Sow.) typical for the Upper Cenomanian of the ee-stage division, which is generally cepted in Europe. Gaudryceras sacya orb.) is present in Cenomian formations Asia and Africa; there are data indicating presence of this form in the Cenomanian the Western Ukraine.

Puzosia cf. gaudama (Forb.), previously ntified and described in the Turonian mations of India and Africa, was also nd in the upper part of Cenomanian strata the neighborhood of Bakhchisarai.

The above forms, found in marls, are nmonly highly deformed. In the Cenomanian marls, pyritized, deformed, and very poorly preserved nuclei of small Puzosia are very common. In the hard limestone layers in the upper part of the sequence, the nuclei of ammonites are as a rule much better preserved.

The only representative belemnites, Neohibolites ultimus (d'Orb.) occur only in the lower and middle series of the Cenomanian sequence of Crimea. It has a wide geographic distribution in the U.S.S.R. (Western Ukraine, Crimea, Caucasus, trans-Caspian), Western Europe and Africa. In Europe the N. ultimus (d'Orb.) is found mainly in the lower zone of the three-stage Cenomanian division.

Aucella, which forms local accumulations in sandy marls in the lower part of the section, should also be mentioned.

The above data on the distribution of the more important fossils in the Cenomanian formations of Crimea are insufficient for our identification of the three stages of the Cenomanian according to the system used in Europe: Lower Cenomanian with N. ultimus (d'Orb.), Middle Cenomanian with Schloenbachia varians (Sow.) and Upper Cenomanian with Acanthoceras rotomagence (Defr.). It appears possible to separate only the lower part of the marls, containing Neohibolites ultimus (d'Orb.), nuclei of Acanthoceras mantelli (Sow.), Schloenbachia varians (Sow.) and Puzosia subplanulata (Scrlut.), and the upper part, in which N. ultimus (d'Orb.) is absent, but which contains Scaphites sequalis (Sow.) and Gaudryceras sacya (Forb.).

A somewhat different division of the Cenomanian is possible on the basis of the vertical distribution of some foraminifera. The Cenomanian formations of the Crimea, as in some other regions of the southern U.S.S.R. and western Europe, contain Rotalipora apenninica (Renz), R. reicheli (Mornod), R. montsalvensis (Mornod), Gumbelina cenomana (Keller), Globigerina infracretacea (Glaesan.), G. gaultina (Moroz.), Globigeri-

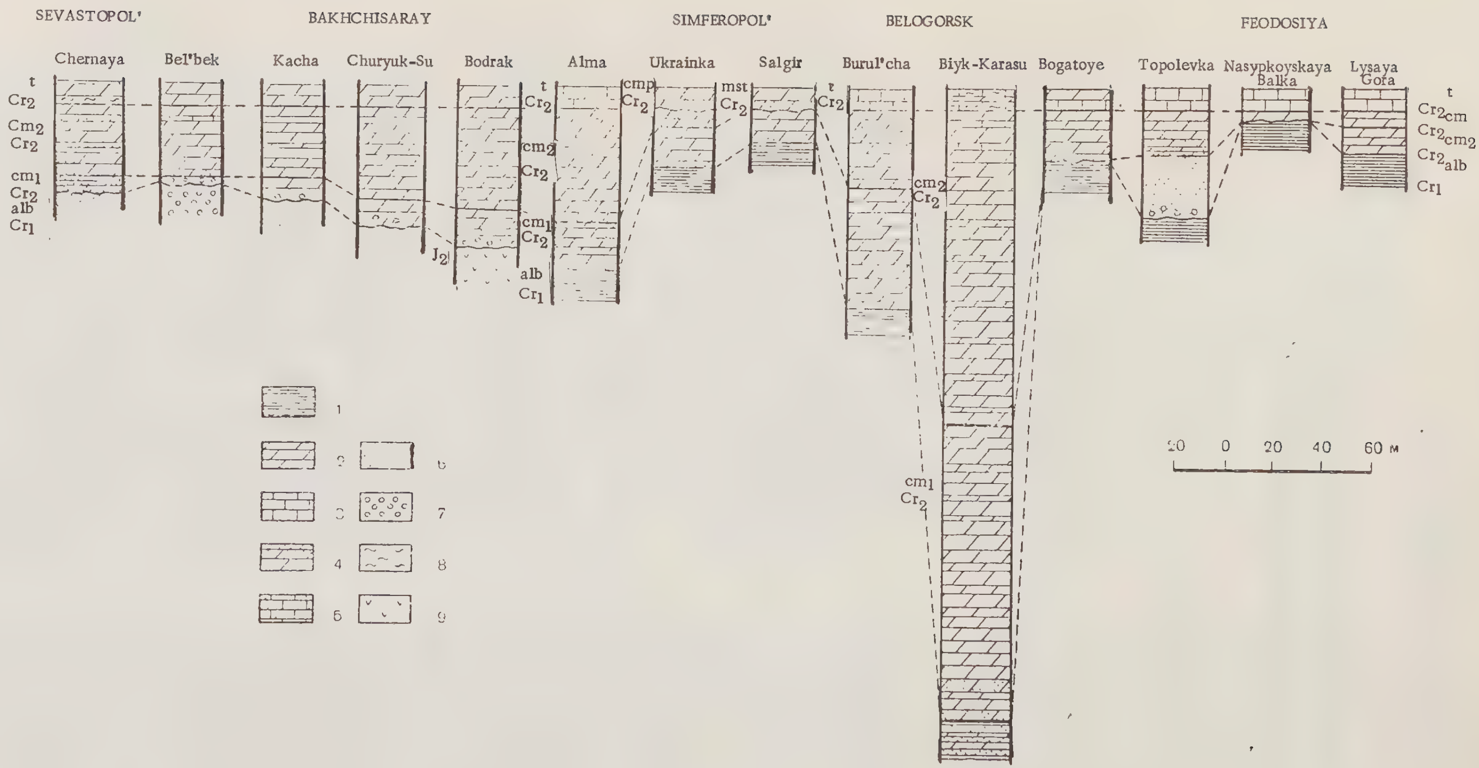

FIGURE 1. Schematic comparison of the sections of the Cenomanian formations of the Crimean mountains (according to N.I. Maslakova). Cr_2^{cm1} - Lower part of the Cenomanian with Rotalipora apenninica; Cr_2^{cm2} - Upper part of the Cenomanian with R. reicheli and R. montsalvensis.

1 - clay; 2 - marl; 3 - limestone; 4 - sandy marl; 5 - sandy limestone; 6 - sandstone; 7 - conglomerate; 8 - flint; 9 - effusive rocks.

nella ultramicra (Subb.), Anomaline baltica (Brotzenu), A. cenomanica (Brotzen), Gibicides jarzevae (Vas.), Bolivinita eouvigeriniformis (Keller), Tritaxia pyramidata (Reuss) and others.

The above forms, except Rotalipora reicheli (Mornod) and R. montsalvensis (Mornod), were identified throughout the section. R. apenninica (Renz) is commonly found in the lower beds of the Cenomanian. R. reicheli (Mornod) and R. montsalvensis (Mornod) are present only in the upper part of the sequence.

Thus, on the basis of the distribution of the representatives of Rotalipora, the Cenomanian formations of the Crimea can be divided into two stages as seen in Figure 1; Cr^{cm1}, characterized by the mass accumulation of R. apenninica (Renz), and Upper Cr_2^{mc1}, containing R. reicheli (Mornod) and R. montsalvensis (Mornod) which are characteristic of the upper part of the Cenomanian of the Mediterranean province.

A similar division based on foraminifera does not coincide with the above two-stage division based on cephalopods. The border between the above-mentioned micro-paleontologic stages is situated below the border based on the distribution of ammonites and belemnites. The step-like distribution of the boundaries according to different groups is obviously not due to coincidence.

As is seen from the scheme represented on Fig. 1, the formations of the Cenomanian stage in the Crimean mountains are both represented by full sections (Biyuk-Karas and Alma Rivers), and sections which are shortened by the disappearance of the lower strata.

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ON THE AGE OF THE NERTCHINSK-ZAVOD GROUP OF POLYMETALLIC ORE-DEPOSITS, EAST TRANS-BAIKAL REGION

by

Yu. P. Pistsov

The age of the polymetallic ore deposits of the Nerchinsk-Zavod group, while not a subject of discussion here, is still not conclusively established.

Most of the polymetallic deposits in this reion are found in Paleozoic carbonate rocks. A considerably smaller number occur in the Jurassic formations. Polymetallic deposits were not found in the Lower Cretaceous rocks. On the basis of these facts the time of formation of the polymetallic deposits is assumed to be post-Jurassic to pre-Lower Cretaceous.

It is obvious that the upper age limit is determined arbitrarily. In the first place, the Lower Cretaceous formations in this region are developed over a considerably smaller area than the Paleozoic and Jurassic formations. Naturally, the probability of finding polymetallic deposits in these formations is directly proportional to the area occupied by the formations, all other conditions being equal. In the second place, the Lower Cretaceous formations in this part of South-Eastern Trans-Baikal occur in a region of depressions, and are usually covered by a thick mantle of Quaternary formations, which makes prospecting much more difficult.

When it is also taken into account that the Lower Cretaceous formations have been incompletely investigated, it becomes clear that the established opinion on the absence of polymetallic deposits in the Lower Cretaceous formations, and consequently in pre-Lower Cretaceous formations, is not based on fact. It also becomes apparent more data are needed for the conclusive solution of this problem. Such data were obtained as the result of datailed investigation of the sedimentary iron-ore deposit in Berezovsk, which is situated on the eastern edge of the Nerchinsk-Zavod group of ore deposits. The stratigraphic section of the Lower Cretaceous formations in the Berezovsk region is as follows: The basal formations, consisting of large friable fragments of rocks and a carbonaceous and argillaceous cement lies unconformably on the eroded surface of Paleozoic and Jurassic rocks. The thickness of the basal formation varies from several tens of centimeters to 120 m. Overlying the basal formation, and in places lying directly on the pre-Cretaceous base, there are conglomerates and siltstones. These rocks are jointly called the clastic phase. The conglomerates consist of angular and slightly rounded fragments ranging in size from 2 to as much as 15 cm. In isolated places conglomerates reach 5 to 8 m. in diameter. The variety of the fragments is fairly uniform and corresponds to the composition of the underlying Paleozoic rocks. The bulk of the fragments consists of several varieties of limestones, phyllite-shales and quartz-sericite shales. The cement of the conglomerate consists of small fragments, having the same composition as the coarser fraction. In extensive areas the cement is replaced by siderite or in the zone of oxidation by limonite; in some cases, the coarser fraction is similarly altered. This is typical of the Berezovsk ore deposits.

The siltstones are gray or light gray, fine-grained rock, with distinct, fine layers. The layers of siltstone are separated by sandstones and argillites.

The thickness of the clastic phase reaches 500 to 600 m. The age of this formation was determined as Lower Cretaceous on the basis of the study of fossil flora and microfauna found in the siltstones.

The nature of the coarse Lower Cretaceous conglomerates indicates that they were formed as the result of destruction of the material provided from the neighboring regions.

Naturally, the material provided by the destruction of all the neighboring polymetallic deposits should be found in the conglomerate. However, due to the easy destruction of sulphide minerals during transportation, and the practical impossibility

of identifying the scattered products of their oxidation in the cement of the conglomerate, the probability of finding the material was very small. Only after several years of detailed study of the Berezovsk iron ore deposit, an iron conglomerate was found containing a fragment of lead ore. This fragment was discovered in the lower part of the clastic phase 50 meters above the base of the Lower Cretaceous formation. The rock containing the ore fragment did not differ from other iron conglomerates. It consisted of slightly rounded fragments, and a sideritized matrix consisting of small fragments. The size of the grains varies from several millimeters to 5 centimeters. The large fragments consist of light-gray and yellow-gray dolomitic limestone. The composition of the small fragments was less uniform. In addition to the rocks described above, they included dark gray limestone, coal siltstone and light brown limestone completely replaced by siderite.

The fragment of ore was a relatively well rounded pebble of light gray dolomitic limestone, 3.5 cm. in diameter. At the edge of the fragment a large, nearly isometric impregnation of galena was found. The impregnation was 7 mm. in diameter. The limestone pebble was traversed by a fine veinlet of cryptocrystalline siderite, which also cuts the galena zone. Several minute grains of galena were observed in the siderite cement around the pebble.

In its mineral composition and its texture and structure, the described ore fragment does not differ from sulphide ores of the neighboring polymetallic deposits. The presence of this fragment in the Lower Cretaceous formation indicates that the polymetallic deposits at the beginning of that period were already exposed by erosion, and were slowly being destroyed.

This proves that the polymetallic ore deposits of the Nerchinsk-Zavod group are post-Jurassic to pre-Lower Cretaceous in age.

Berezovsk Geologic Prospecting Party
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REVIEWS AND DISCUSSIONS

ON M. N. SAIDOV'S ARTICLE "CONTINENTAL MESO-CENOZOIC DEPOSITIONS OF THE DZHUNGARA DEPRESSION"

by

L. I. Uvarov

M.N. Saidov's paper raises certain critical questions regarding its main content.

1. The title of the paper does not describe the content. The author quotes some data on the stratigraphy of some separate regions at the foot of the Tien-Shan, and Altai Mountains, from which a discussion of the stratigraphy of the inner portion of the Dzhungar depression seems impossible in our opinion.

While deposition was progressing, the composition of the deposits was sharply and appreciably changing away from the rising massif of the Tien-Shan and Altai Mountains, as well as toward the central part of the depression.

Therefore, we believe that the author's stratigraphic division of the continental deposits of the entire depression cannot be valid when it is based on study of the premountain zone alone.

A better conclusion would be that the deposits of the central part of the depression are of lacustrine origin, of very uniform composition and difficult to differentiate.

2. The author writes that, "on the basis of paleontologic determinations of the continental deposits -- deposits of Triassic, Jurassic, Cretaceous, and Tertiary age -- were identified." These determinations should be considered as schematic and disputable.

The paper presents no paleontologic comparison of fauna from the Dzhungar depression with the sections studied in the neighboring regions, nor even an approximate correlation of the Dzhungar sections with the international geochronological table.

3.- The author states that "Triassic formations are developed only in the southeastern part of the Dzhungar depression." We believe that this is disputable. It would be more correct to say that the Triassic formations are exposed only at the foot of the Bordo-Ola ridge, but that so far their distribution is unknown for the deeper parts of the Dzhungar depression. We have the impression that these formations are widespread along the marginal flexure of the depression, but that they have not been yet exposed by erosion.

4. The division of the coal-bearing Jurassic suite into two parts, according to the presence of multicolored rocks in the section is quite unjustified. Such rocks are found in all the parts of the section and no rule regarding their spatial distribution could be derived. This was observed by us in several sections in the Fukan and Santai regions.

5. When describing the lithologic composition of the Jurassic coal-bearing formations, it should be remembered that the coarse clastic material very quickly disappears in the direction of the depression. This phenomenon can be explained by assuming that during the deposition of the Jurassic formations, continuous pulsating movements took place in the Paleozoic mountainous formations surrounding the depression, which provided the material for the accumulation of the Jurassic deposits. It could also be assumed that in the deeper part of the Jurassic formation greater uniformity of lithologic composition and a greater content of clay would be observed. We have observed this during the study of large sections of the Jurassic (and also Cretaceous and Tertiary rocks), at various distances from the mountains, both at the southern and northwestern edges of the Dzhungar depression.

6. In the paper, the Jurassic coal-bearing formation in the region of the Karama Mountain was described. (In this case it would be more correct to speak of a hill, not a mountain.)

The author writes, "The middle part of the lower half of the coal-bearing suite is exposed in the Karamay Mountain region -- the deposits are 370 m. thick."

This is quite incorrect. The uppermost

part of the upper half of the coal-bearing suite is exposed in the Karamay region, rather than the "middle part of the lower half of the coal-bearing suite."

This was proved by our work in the region when we identified Upper Jurassic formations of the Chiyguy suite. These formations overlie the coal-bearing rocks without visible unconformity. In addition, we were able to compare the deposits of the Chiyguy suite with the corresponding deposits of the southern edge of the Dzhungar depression. The difference was limited to their thickness, and did not extend to the lithology. The thickness of the Chiyguy suite in the Karamay region is 115 m., and that of its corresponding deposits about 700 m. Consequently, M.N. Saidov gives an incorrect thickness for these deposits (370 m.). Farther away from the mountains, the thickness of the deposits increases rapidly and, judging from geophysical data, reaches more than 3,000 m.

7. In describing the sections of the Cretaceous deposits, which border the southern edge of the Dzhungar depression, the author does not attempt to draw any conclusions from the quoted data. In our opinion, he should have mentioned the general rule, applicable to the sections he described; namely, that the greatest thickness of the Ishakdavan and Karadzhal suites (arbitrarily referred to the Lower Cretaceous) is observed at the terminations of the large fractures, intersecting the northern slopes of East Tien-Shan.

In describing the Cretaceous formation at the southern edge of the depression, we determined the thickness of the Karadzhal suite to be 400 m. along the strike of a large fracture, and only 130 m. at a location 25 km. to the east of it, in a section along a small fracture. In addition, the work carried out in 1955 in the Fukan region (Fan Chan-Lun, Van Da-Dyun, et al.) indicated that previous investigators caused the confusion regarding the age of the Ishakdavan and Karadzhal suites. In fact, the Karadzhal suite is older than the Ishakdavan suite. The error was due to the fact that the suites were found in an overturned limb of a fold.

8. Describing the Tuguluk suite (Upper Cretaceous), M.N. Saidov states that "west of Urumcha, the Tuguluk suite consists of three groups." This is not true. The three groups of the suite were also found by us east of Urumcha, more than 100 km. distant. Until then, M.N. Saidov and N.P. Tusyev divided these deposits into four or five groups. We also studied the three groups of the Tuguluk formation in the northwestern edge of the Dzhungar depression.

The author writes that the deposits of the suite "lie very unconformably on the Jurassic coal-bearing suite and on the Paleozoic... the thickness of the suite varies between 25 and 77 m." This, in our opinion, is a serious error. In the first place the Tuguluk suite in the Karamay region lies conformably on the Karadzhal suite, and, farther on, it lies transgressively on the Paleozoic rocks. In the second place, in the region of the lower course of the Dyam River, the suite lies only transgressively and monoclinally on the Paleozoic rocks. In the third place, the thickness of the suite does not vary between 25 and 77 m., but in some regions it is 265 m. or even 800 m. thick. In the fourth place, the Cretaceous formation lies very unconformably in one place only, that is, the Asphalt Hills region in Karamay, having an area of about 0.25 ha.

9. In the schematic description of the Tertiary formation, the author for some reason does not show that the straw-colored suite is also found in the northwestern edge of the Dzhungar depression. According to our data it is 35 m. thick in the Karamay region and south of it. We traced the suite to the Urkho region, where its visible thickness is 60 m.; it rests unconformably over the Cretaceous formation, and in places lies transgressively on Paleozoic rocks. In the straw-colored suite we found abundant fauna, apparently identical with the fauna of the same formation in the southern edge of the depression.

10. The article of M.N. Saidov includes the "Survey map of the Dzhungar depression." For the Karamay and Urkho regions, this map is obsolete and inaccurate. South of Karamay, lake Ayran-Kul' is shown. This lake does not, and never did, exist. Previous investigators erroneously considered a large basin to be a lake. This basin was sometimes flooded by waters flowing from the Dzhair ridge and by the overflow from lake Erik-Nor. The channel along which the water from the lake flows was at one time considered by V.A. Obruchev to be the Kupyr River, which in reality does not exist and never existed. In 1954 we discovered a large lake 100 km. east of Karamay and 70 km. southeast of Urkho. This lake was called Manasskoye. It receives the waters of the Manas River, flowing from Tien-Shan, and of the Kobuk River, originating in the Altai. It is situated in an inaccessible part of the Dzhungar desert, and we believe that for this reason it had not been discovered earlier. The lake is about 100 km. long and 20 km. wide. It has salt water (in the central part the salt content is more than 100 g./1.). Its depth is probably not less than 5 to 8 m.

11. All our critical remarks on M.N. Saidov's paper are based on factual data which we studied.

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CHRONICLE

CONFERENCE ON THE METALLOGENY OF THE CAUCASUS

In May 1957 an interdepartmental conference on the problems of Caucasian metallogeny was held by the Caucasian Institute of Mineral Raw Materials (KIMS). It was attended by representatives of geologic organizations from Trans-caucasian republics, Northern Caucasus, Moscow, and Leningrad.

The conference, which was concerned with the compilation of the 1:500,000 scale metallogenic map of the Caucasus, was convened in connection with the work of Academician N.S. Shatskiy's committee dealing with "laws regulating the distribution of mineral resources." A number of people participated in the analysis of the problem.

O.D. Levitskiy, Associate Member of the U.S.S.R. Academy of Sciences (IGEM, U.S.S.R. Academy of Sciences) and Committee on "Laws Regulating the Distribution of Mineral Resources", emphasized the need for intensifying methodical research in the field of prospecting for "sealed" deposits. He recommended that research be concentrated on a complex study of the distribution of sedimentary and magmatic deposits.

V.G. Grushevoy, Doctor of Geologic and Mineral Sciences (VSEGEI), described the principles of regional metallogenic research and the method of compiling small scale metallogenic maps which had been developed by the VSEGEI staff while it was still under the direction of Yu. A. Bilibin. The speaker emphasized that the classification of structural-metallogenic zones and genetic types of deposits adds to the already well-known charts.

Three papers dealing with problems of tectonism in the Caucasus were read.

P.D. Gamkrelidze, Associate Member of the Academy of Sciences of the Georgian S.S.R. presented a tectonic classification of Georgia. He outlined the following breakdown by zones: Bol'shoy Kavkaz, Georgian block (the western part of the Transcaucasian intermontane flexure) and the Adzharo-Trialetskaya zone, Artvino-Somkhitsk block (part of the Somkhitsk-Karabakh zone). The first was subdivided into the geoanticline of the Main Ridge and the folded system of the southern slope; the second was subdivided into the Rachinsko-Trialetskaya, Svanetskaya, Abkhazskaya, and Sukhumsko-Dushtskaya zones. The Georgian block was divided into the Kolkhidskaya, Dzirul'skaya, Kartalinskaya and Tsiv-Gomborskaya zones. The Adzharo-Trialetskaya folded system was divided into the Northern, Central and Southern zones. The Artvino-Somkhitskaya block was subdivided into the Dzhavakhetskaya, Bolnisskaya, Borchalinskaya, and Asuretskaya zones.

E. Sh. Shikhalibeyli, Candidate of Geologic and Mineral Sciences (Azerbazhan S.S.R. Academy of Sciences), described the geologic and structural characteristics of the territory in that region. The basic geotectonic units to be distinguished there are as follows: the Ciscaucasian advanced flexure, the Bol'shoy Kavkaz elevation, the Kurino-Rionskiy intermontane flexure, the Malyy Kavkaz elevation, and the Anatolian-Iranian intermontane flexure. Numerous structural forms (anticlinoria and sinclinoria) were distinguishable within each of these. On the basis of this material, the speaker followed the history of the geologic formation Azerbaydzhan.

A.T. Aslanyan, Candidate of Geologic and Mineral Sciences (Geological Administration of the Armenian S.S.R.), in his report on the tectonic framework and metallogeny of Armenia, emphasized the adaptability of ore mineralization to tectonic zones. According to his data, in the southern part of Malyy Kavkaz a plutonic break is developing which is causing spatial distribution of endogenous deposits prevalent to the north of the break line and absent to the south of it.

Several papers dealt with magmatic activity of the Caucasus.

G.D. Afanas'yev, Associate Member of the U.S.S.R. Academy of Sciences, presented a paper with much material lending itself to broad generalizations. According to the new data he cited the Dar'yal'skiy massif, and the granitoid veins crossing it containing the Kistinsk and Tsiklaursk formations, classified by V.P. Rengart as lower Jurassic, are

of Paleozoic age. Afanas'yev broadened the young volcanic region in his paper, and classified the Indyuk Mountain region as a part of the post-Jurassic magmatic formations. He considered the El'dzhurtinsk granitoid of the Tyrny-Auz formations as Tertiary.

On the basis of recent data, the ultrabasic rocks of Nizhnyy Teberd' were classified as Lower Carboniferous rather than Upper Silurian -- Lower Devonian. They were likened to the ultrabasic rocks of the Urushtenskiy group. This fact, together with the data quoted on late potash metasomatism of the granitoids in the northern Caucasus, lead the author to the general conclusion that two cycles took place in the Caucasus: the Paleozoic and the Mesocenozoic. The former covers a period of 150,000,000 years. In the Cambrian-Silurian period, there was also a development of ophiolite formations. This association of early rocks is characterized by high sodium content, and is linked with the evolution of the basalt cover of the Earth's crust. A later association of granitoid rocks was accompanied by potash metasomatism. The second cycle, covering a span of 120,000,000 years, corresponds to the development of the Transcaucasian geosyncline. During this period, magmatic activity occurred in the Northern Caucasus on a smaller scale.

Professor G.M. Zaridze (Georgian Polytechnic Institute) gave an age breakdown of magmatic rocks in Georgia, which is different for the Bol'shoy Kavkaz and Malyy Kavkas folds. A paper covering similar material on Azerbaydzhan was read by Sh. A. Azizbekov, Member of the Azerbaydzhan S.S.R. Academy of Sciences.

Problems involving the metallogeny of the Caucasus and individual parts of it were covered in five papers.

G.A. Tvalchrelidze, Candidate of Geologic and Mineral Sciences (KIMS), requested that principles of metallogenic analysis developed by the staff of the VSEGEI be generally observed.

Noting pecularities in the tectonism, magmatism and metallogeny of the Caucasus, the speaker mentioned certain corrections in the general development of the chart of shifting belts. In particular, he pointed out three geotectonic stages in the formation of the Caucasian geosinclinal region, and three corresponding magmatic cycles -- Caledonian, the Hertzynian and the Alpine, as well as three metallogenic epochs. The most recent stage was subdivided, on the basis of manifestations seen in the Bol'shoy Kavkaz and Malyy Kavkaz, into the Jurassic and the Cretaceous-Tertiary Sub-stages. Each stage, cycle and epoch was further divided into three stages related to the principal phases of folding. This was followed by an interruption of geosinclinal development, consolidation, and regional elevation of a given zone. On this basis, the stages might be described as prefold, fold, and postfold. Basically these correspond to the early, middle and late stages described by Yu. A. Bilibin. Each is typified by specific facies, structures, magmatic rocks, and ore deposit development.

Material on Caucasian metallogeny which was illustrated by tables and distribution charts based upon the various epochs and their stages was analyzed using this principle. The same methods were used in a model of a metallogenic map which was displayed.

The map, compiled on a scale of 1:1,000,000, was a schematic geologic map. It was divided in accordance with the approximate outlines of the tectonic zones delineated by K.N. Paffengol'ts and P.D. Gamkrelidze, comprising 17 structural-metallogenic zones of various types. The metallogenic epochs are indicated by varicolored cross-latching, and the stages by different types of hatching. The location of the various stages is indicated by signs differing in form and size, and the principal metals (types of deposits) by various colors. This method made it possible for the speaker to illustrate the probable areas in which various metals may be found. Further development of these principles, using the same methods, may be used to compile a metallogenic map on a scale of 1:500,000.

I.G. Magak'yan and S.S. Mkrtchyan, Members of the Armenian S.S.R. Academy of Sciences, presented a paper on the interrelations between tectonism, magmatism and metallogeny as shown in the Malyy Kavkaz period. They distinguished three basic tectonic-magmatic groups -- Alaverdi-Kafan, Pambak-Zangezur, and Sevano-Amasi -- on the basis of their specific geologic structure, the common history of their formation, and metallogeny. On this basis, six magmatic cycles and metallogenic epochs can be distinguished. They are as follows: Paleozoic (Au, Sn, As, Bi), Postmiddle-Jurassic (pyrite mineralization of Cu, Pb, Zn, Ba), Pre-Cenomanian (Fe, Co), Pre-Cretaceous and Eocene (Cr, Pt, Ni, Cu, Mn, Fe, Pb, Zn, Au), Miocene (Mo, Cu, Sb, Pb, Zn), and Mio-Pliocene (Au, Te, Bi, Hg, As, Sb). Distinct ore formations are allocated to each belt.

It should be noted that in analyzing the metallogeny of the Caucasus as a whole, it was impossible (in the opinion of the speaker) to consider the specific nature of each magmatic "cycle." Furthermore, "transitory" metals were found in ore deposits of various

ıetallogenic epochs. Thus, epochs are considered as covering a considerably greater .me interval. In particular, the Main Ridge one of the Bol'shoy Kavkaz contains some ıolybdenum, tin, arsenic, tungsten, gold of ıe Carboniferous (Kti-Berda, Azget) of the ırassic (Tirny-Aud), and Tertiary (Sana, arobi) ages. Polymetallic deposits of the liddle Jurassic (Tkhmori, Amtkhela), Upper ırassic (?) (Dzyshra, Apshra) and Tertiary Jpper Kvaya) ages were found in the Suk-ımsko-Dzhavskaya zone. Pyritic deposits of ıe Middle Jurassic (Chiragidzor, Kadabek), retaceous (Shamlug, Madneuli) and Tertiary ') (Shagali-Eylar) ages were noted in the ɔmkhitsk-Karabakh zone. Metals typical of given age have been discovered; for exam-.e, antimony, mercury and arsenic are ɔund in realgar, while orpiment is found ıly in young, low temperature deposits in .e Bol'shoy and Malyy Kavkaz.

In our opinion, the specific nature of a ven structural-metallogenic zone is not ɔnditioned by metallogenic epochs, but by e development of its specific stages.

In his report on the metallogeny of eorgia, Professor A. Ye. Bendaliyani eorgian Policethnic Institute) separated 10 e-bearing belts, zones, and points. He escribed the arsenopyrite-rare metal and ɔpper-pyrrhotite belts of the southern slopes the most substantial. In his resume he ɔinted out the association of the rare metals th intrageosynclines and polymetals with trageoanticlines; the spatial-paragenetic sociation of mineralization with small trusions; the multiple stages of mineraliza-ɔn; and the large role of tectonics and the st rock in mineral localization. In conclu-ɔn he lined out, in order of importance, e future problems of investigation of eorgia's ore deposits.

Some statements of the speaker regarding e intersection of ore belts and his broad commendations on future exploration of any Mining Administration Offices were iticized (V.G. Grushevoy, N.A. Khrush-ev).

Academician of the Azerbaydzhan S.S.R. ademy of Sciences, M.A. Kashkay, pre-nted the image of the metallogeny of erbaydzhan created by the collective of ologists of the Geologic Institute, Azerbayd-an S.S.R. Academy of Sciences and the ologic Administration of Azerbaydzhan S.R. His report included a great deal of ctual data on the ore-bearing areas and neral deposits of the republic. However, V.G. Grushevoy pointed out, he did not rry through the idea of regularity of spa-l distribution which actually enters into problems of metallogeny. Neither was this idea properly reflected in the map on metallogeny.

Touching on the question of North Caucasian metallogeny, Candidate of Geologic and Mineral Sciences, L.P. Kharchuk (KIMS), enumerated the broad problems of future geologic work. He pointed out the need for defining more accurately the many problems of stratigraphy, magmatic activity, tectonism, exploration of mineral deposits, ore fields, etc. These are essential problems. We believe, however, that generalizations on metallogeny, specifically preparation of a 1:500,000 scale map on the metallogeny of the Caucasus, should be made parallel with the solving of general geologic problems. Obviously, any new investigations will to some extent correct and perhaps even radically change current schemes.

The speaker proposed a new and interesting scheme of structural zoning of the North Caucasus in which transverse (Anticaucasian) structures occupy an important position. Presence of the latter L.P. Kharchuk verifies by the decrease in the thickness of sedimentary rocks which is observed in longitudinal sections of elevated zones of the southern slopes (Dzirul'sk, Svanetsk, Tsiv-Gomborsk), by geophysical data, and other factors.

Seven papers covering different problems of the metallogeny of the Caucasus were presented.

Professor G.D. Azhgirey (MGU), informing on the results of the MGU Caucasus Expedition presented data which made it possible to identify volcanic depositions, formerly believed to be Middle Devonian, as Cambrian in one instance and as Lower Carboniferous in another. This raised the question of the different ages of the pyrite mineralization in the frontal ridges of the North Caucasus.

On the basis of data on the intensity of tectonic dislocations in the Sadon area, G.D. Azhgirey related the basic disturbances, and consequently, the mineralization to the Tertiary age.

The intensity of the Middle-Jurassic tectonic phase must be considered as substantial since it was observed in many places of the Trans-Caucasus, in the eastern geosinclinal zone of the North Caucasus, where the phase was quite active. After this phase the geosyncline was practically closed.

Professor V.I. Smirnov (MGU) presented a critical review of the principles of G. Shneyderkhen's hypothesis about regenerated deposits. According to the speaker, a number of metals in the Caucasus, such as molybdenum, arsenic, copper, tungsten and

other, form less important concentrations in older deposits than in younger ones. In this area the evidence does not support G. Shneyderkhen's theory. In this relation only the complex polymetallic -- rare metal, low temperature deposits of the southern slope are of interest. Material on these deposits should be analyzed with the role of regeneration in the formation of deposits in mind.

Candidates of Geologic and Mineral Sciences, I.A. Shirvanzade (Azerbaydzhan S.S.R. Academy of Sciences) and E.T. Bayramalibeyli (Azerbaydzhan Nonferrous Metal Exploration Administration) presented factual material on the iron ore deposits of the Caucasus. Until now, industrial diversions were established only for the Dashkezan deposit and, possibly, for several other skarn-type deposits. However, the sedimentary carbonate iron ore accumulations in Mesozoic depositions of the North Caucasus are also promising.

Doctor of Geologic and Mineral Sciences, A.D. Kalandadze (KIMS), reporting on mercury in the Caucasus, presented data on deposits and showings of cinnabar which form a number of zones on the northern and southern slopes of the greater Caucasus. They also outlined the problems of future work in this field.

Candidate of Geologic and Mineral Sciences, P.S. Saakyan (VIMS), outlined a classification of the bedded polymetallic deposits of the Caucasus. He then described in detail the conditions under which the Privol-nensk deposit in the Armenian S.S.R. was formed. He expressed himself in favor of the possibility that this and other similar deposits are of sedimentary-metamorphic origin.

Candidate of Geologic and Mineral Sciences, G.I. Kerimov (Azerbaydzhan S.S.R. Academy of Sciences) reported on the pyrite and chalcopyrite deposits of Azerbaydzhan and the existing views that these deposits are related to the formation of subvolcanic acid rocks and granitoids. According to the speaker's data the pyrite deposits differ sharply from the chalcopyrite deposits. G.I. Kerimov believes that quartz porphyny, with which many investigators are inclined to associate the mineralization, does form a favorable medium. Even within the limits of the Kedabek deposit the speaker identifies an age difference for the pyrite and chalcopyrite. He believes that the pyrite is of Middle-Jurassic and the chalcopyrite of Neocomian age. In both instances, intrusive granitoids were the source of the ore solutions.

We believe that the author somewhat overextended the concept of "mineralization phase." It is difficult to substantiate such a long formation process for a single deposit, which at that is a rather simple one. Neither can we ignore the fact that within the entire Somkhitsk-Karabakh zone the pyrite mineralization is monotonously coordinated with the subvolcanic (spilite-keratophyre) formation. This is characteristic for other analogous zones as well. While referring only to Azerbaydzhan deposits (Chiragidzor, Kedabek and other) the author should also consider data which contradicts his broad generalizations (Madnevli, Shagali-Eliar and other).

Academician S.S. Mkrtchyan (Armenian S.S.R. Academy of Sciences) presented results of the investigations in the Alaverdi ore district. The new data disproved existing opinions on the stratification of the mineralized area and its association with acid effusive rock and its tuff. The mineralized area encompasses a substantial vertical interval. It is distributed in nearly all the rock formations of the area and is in conformity with their composition and structures favorable to mineralization. The speaker did not reach any definite conclusions regarding the age or the genetic relation of the mineralized area to magmatic activity. There was definite need for this type of interpretation in his report which he co-authored with I.G. Magak'yan.

Among those who participated in the discussions, most deserving of mention is Doctor of Geologic and Mineral Sciences, Ye. A. Radkevich (IGEM, U.S.S.R. Academy of Sciences), with his informative report on methods of metallogenic map preparation; N.I. Khitarov (GEOKhI, U.S.S.R. Academy of Sciences); N.A. Khrushchev; and others.

The resolutions of the Conference recommend further clarification of the remaining problems regarding stratigraphy, paleogeography, tectonics, magmatic activity, and metallogeny of the Caucasus; widening of the work on the absolute age determination of rocks and ores; preparation of a structural zone classification on the geology and magmatic activity of the Caucasus; preparation (on the basis of G.A. Tvalchrelidze's model map on the metallogeny of the Caucasus) of the first draft map on a scale of 1:1,000,000 for subsequent use by VSEGEI in the preparation of the 1:2,500,000 scale map of the metallogeny of the U.S.S.R.; preparation by geologic organizations of the Caucasus of of large scale metallogenic maps for individual ore-bearing areas.

A committee of 13 was selected to supervise this work.

G.A. Tvalchrelidze

FIRST CONFERENCE
OF THE SECTION ON HISTORY
OF GEOLOGIC-GEOGRAPHIC SCIENCES,
SOVIET NATIONAL ASSOCIATION
OF NATURAL AND TECHNICAL
SCIENCE HISTORIANS

The First Conference of the Soviet ational Association of Natural and Technical :ience Historians, which is a member of the ternational Union of History and Philosophic :iences, took place at the end of June 1957 Moscow. A committee of the Soviet ational Association was elected at the con-rence and sections were organized for the ırious areas of science history, including ıe for the History of Geologic-Geographic :iences. Professor and Doctor of Geologic ıd Mineral Sciences, G.P. Gorshkov was ected as chairman of the section. Active ember of the R.S.F.S.R. Academy for edagogic Sciences, Professor and Doctor of eographic Sciences, B.P. Orlov was elected vice chairman, and Candidate of Economic :iences, G.S. Tikhomirov as science secre-ry.

At the first meeting Professor G.P. Gorsh-v presented a paper on the work and ob-ctives of the section.

The objectives of the section are to study e history of ideas, theoretical images an eir relation to practical work; history of vestigation of useful minerals and ore de-sits in relation to the development of the sic branches of the mining industry; his-ry of large geographic and geologic developments of the Soviet era; and creation of large monographic as well as small volume work on the history of geology and geography. At the same time, it is necessary to put into order publication of the biographies of the domestic scientists -- geographers and geologists.

Another important objective in the preparation of material for the International Congress of Science Historians which is to take place in 1959 in Barcelona.

The following participated in a discussion of questions raised by Professor G.P. Gorshkov: Prof., Doctor of Geographic Sciences N.N. Zubov, Member Correspondent of the Academy of Pedagogic Sciences A.I. Solov'-yev, Candidate of Geographic Sciences V.V. Tsybul'skiy, Chief Editor of Geographgiz B.V. Yusov, Candidate of Geologic and Mineral Sciences Ya. M. Svet, Lecturer I.I. Starostin, Candidate of Geographic Sciences G.V. Yanikov, Candidate of Geographic Sciences N.A. Solntsev, Candidate of Historic Sciences A.A. Kuzin, Candidate of Geographic Sciences A.F. Plakhotnik, and Candidate of Economic Sciences, G.S. Tikhomirov.

In his concluding statement Prof. G.P. Gorshkov pointed out the great value of the suggested proposals which will be included in future work of the Section on History of Geologic-Geographic Sciences.

G.S. Tikhomirov